MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. CXLI.

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Corrigenda of vol. cxl., *for* "cxxxix. p. 546, line 7," *read* "cxxxviii. p. 546, line 8."

THE INSTITUTION OF CIVIL ENGINEERS.

SESSION 1899-1900.—PART III.

SECT. I.—MINUTES OF PROCEEDINGS.

6 February, 1900.

Sir DOUGLAS FOX, President,
in the Chair.

It was announced that the Associate Members hereunder mentioned had been transferred to the class of

Members.

HERBERT EDWARD ALLEN.
CHARLES ANTHONY, Jun.
KENNETH FINDLATER CAMPBELL.
HERBERT TAYNTON FOORD.
CHARLES HEYLAND FOX.
RICHARD HENRY GOOD.
JOHN GOODMAN.
THOMAS ROBERT GRIFFIN.
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JAMES LENNOX HOUSTON.
HENRY HOLMES JELLETT, B.A.I. (*Dubl.*)
THEOPHILUS MICHELL.
WILLIAM PURCELL O'NEILL.
ROBERT PEIRCE.
HARRY SHOOSMITH.
CHARLES PRATT SPARKS.
PERCY KENDALL STOTHERT.
JAMES NAAMAN TAYLOR.

And that the following Candidates had been admitted as

Students.

JOHN BROWN.
JOHN MARTIN CLARK.
HENRY FARRANT.
WALTER LEE.
HAROLD LOMAS, B.Sc. (*Victoria.*)
JOSEPH OATES.
THOMAS ROLLS RENFREE.
SUTHERLAND ROBERTSON, Jun.
ROBERT GREAVES WILLIAMS-ELLIS.

The Candidates balloted for and duly elected were: as

Members.

JOHN BOGART.
SEBASTIAN ZIANA DE FERRANTI.
JOSEPH HUTCHINSON HARRISON.

Associate Members.

HENRY REGNIER CAMPBELL ADAMS.
SIDNEY ALLEN.
ATHOL LANCELOT ANDERSON, Stud. Inst. C.E.
FRANK BAKER, B.Sc. (*Victoria*), Stud. Inst. C.E.
JOHN BRYCE.
CHARLES LESTOURGEON BUSHELL, Stud. Inst. C.E.
JAMES MARSHALL COWAN, B.A. (*Cantab.*)
ERNEST HENRY ESSEX.
MICHAEL BIRT FIELD, Stud. Inst. C.E.
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THOMAS ANDREW GAILEY, B.E., B.A. (*Royal.*)
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WILLIAM GEORGE HIBBINS.
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JOHN MACKENZIE KNIGHT.
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HUGH OLDHAM.
ROBERT ROWAND.
ROBERT JOHN BEVIL SHARPE.
JOHN HUW WILLIAMS.
CHOSAKU YOSHIMURA.

An Associate.

TERUGORO FUJII.

(*Paper No. 3195.*)

"Moving Loads on Railway Underbridges."

By WILLIAM BEAN FARR, Assoc. M. Inst. C.E.

THE use of uniformly distributed moving loads is the most convenient and expeditious method of calculating the strengths of the rail-bearers and main girders of railway underbridges, where the rails run directly over the main girders, or where the cross girders are spaced sufficiently close to render the load transmitted by them to the main girders a practically uniformly distributed one. Where the cross girders are spaced at greater distances apart than is compatible with this, the actual moving loads transmitted by the cross girders, due to the heaviest locomotive or boiler truck, etc., in use, must be ascertained; and the stresses in the main girders must be calculated from the loads so obtained. Generally speaking, however, for underbridges on British railways, the method of using uniformly distributed loads can be satisfactorily applied in the majority of cases.

The actual loads on girders due to locomotives and other moving loads are not uniformly distributed, but consist of weights concentrated at various distances apart. A parabola can, however, be

constructed for each span, such as to include all bending moments due to the passage of the actual concentrated loads, and from this a uniformly distributed load can be computed which can be used in place of the actual loading.

In the case of underbridges of the spans considered in this Paper, 5 feet has been taken as being the minimum span for which it is likely that girders will be used, and 100 feet as the limit of span for which it is economical to employ plate girders, and which may also reasonably be taken as covered from end to end by locomotives only.

Passenger trains, and to a less extent goods trains, may frequently be seen drawn by two locomotives; and three or more engines may be seen moving coupled together on English railways; so that it is evident that, up to the maximum span of 100 feet, it is reasonable to take the span as entirely covered by locomotives. Bridges of more than 100 feet span will generally be constructed with lattice girders to which the method of using uniformly distributed loads is not applicable with accuracy.

The action of a load moving at high speed (and by this is meant the speeds customary on British railways) is very different from that of a dead load of equal intensity; and considerably increased stresses are imposed on the girders of underbridges from the following causes, which are important factors, more especially in the case of the smaller spans, where the moving loads constitute the chief and almost the only load to be carried.

(*a*) The extra stresses due to impact caused by the load being suddenly applied.

The results of early experiments tended to show that loads moving at the speeds customary on railways were as destructive as dead loads of at least twice their amount; but in the case of railway bridges the load is not applied with sufficient suddenness, and the time occupied by the loads in passing over is insufficient for the attainment of molecular equilibrium in the metal of which the girder is composed, and consequently the full effect of the impact is not developed. It is found, however, from the deflections of girders with loads at rest and with the same loads passing over at speed, that there is some increase in the latter case, the amount of increase being inversely proportional to the length of the span.

(*b*) Extra stresses due to the badly laid or maintained state of the permanent way over the bridge. This, together with the shock from rail-joints (which should be avoided on all bridges where the length of the span is less than that of the rails em-

ployed), may cause considerable additional stresses by increasing the vibrations which are inseparable from the passage of loads at high speeds, and which may have the effect of multiplying the number of bendings of the girders and of increasing the deflections, especially if the "period of vibration" of the bridge happens to synchronise with the "period of application" of the loads.

Some interesting experiments bearing out this were made by Professor Robinson for the State of Ohio Commission in 1884, and the Author has in mind a case coming under his own observation where the passage of the wagons of goods trains caused considerably more vibration and deflection of the girders of a bridge than did the locomotives drawing the trains, or than was caused by the passage of passenger trains at a high speed. In this case, the wheels of the wagons, each loaded to about the same weight, and spaced at almost equal intervals apart throughout the train, had the effect on the girders of a load being removed and replaced at regular intervals, with the result that the vibrations were to a certain extent cumulative. It is also worthy of notice that at certain moderate speeds the vibrations were greater than when the wagons passed over at a high speed. The vibrations and deflections in this case were registered by an automatic recorder, in charge of a man whose duty it was to record the nature of the train passing over. The observations extended over a period of some weeks, during which time some hundreds of trains passed over the bridge.

(*c*) If the locomotives in use on a railway are badly balanced, the stress on the girders may be increased to a very great extent, as was shown by the experiments of Baron von Weber. The Author has in mind two classes of locomotives on a British railway, one class being almost perfectly balanced and the other class as badly balanced as it is possible to be; the former, although weighing some tons more than the latter, cause much less deflection of the girders of the bridges and pass over them quite silently, while the badly balanced locomotives run over them very noisily.

(*d*) The angle of obliquity of the connecting-rods of the locomotives causes an additional stress on the girders, due to the steam-pressure in the cylinders, by the thrust on the slide-bars tending to lift the engine off the leading end and so increasing the load on the driving-wheels. Where the cylinders are placed at an inclination, as is frequently the case, this effect is increased.

In addition to the above, which cause increases in the stresses on the girders, it is necessary to take into account the loss in

sectional area of the girder, caused by the frequent scrapings and cleanings of the surface of the metal when being painted. This loss, though small, should be allowed for by slightly increasing the original cross-section of the girder.

Since the early days of railways, the Board of Trade have exercised a statutory power of inspecting and testing bridges constructed for passenger traffic, prior to the railways being opened; but while specifying the nature of the loads to be taken in designing the girders of underbridges, they have not, up to the present time, except in the case of cast-iron girders, required any allowance to be made for impact (*a*) and the other factors (*b*, *c* and *d*) mentioned above; and previous to 1849 they had issued no rules for the strength of bridges either of cast iron or wrought iron. In 1847 a Royal Commission was appointed to "enquire into the conditions to be observed and to form rules for the application of iron to structures subject to concussions and vibrations," and after due investigation and taking the evidence of technical experts, they made,[1] in 1849, certain recommendations with respect to cast-iron bridges; they also recommended that all bridges under 40 feet span should have special provision for the increased stress caused by a rapidly moving load. These recommendations were issued as instructions to the inspecting officers of the Board of Trade immediately after the issue of the report of the Commission. The recommendation as to cast-iron bridges was substantially the same as the present Board of Trade rule for such structures, viz., "that the breaking weight of a cast-iron girder must be not less than three times the permanent load due to the superstructure added to six times the greatest moving load that can be brought on it." The use of cast iron in railway underbridges is now prohibited, except "in the form of arched ribs, where the metal is entirely in compression" (which is, by the way, an impossibility under ordinary conditions with a moving load). It was not until 1859 that any rules were issued with respect to wrought-iron bridges, when a stress of 5 tons per square inch was fixed as the maximum, this being based, according to Sir Henry Tyler, on an ultimate strength for wrought iron of 20 tons per square inch in both tension and compression, thus giving a factor of safety of 4 for dead and moving loads combined. In 1877 the rules were amended so as to permit the use of steel, the

[1] Report of the Commissioners appointed to inquire into the Application of Iron to Railway Structures.

limiting stress on which was fixed at $6\frac{1}{2}$ tons per square inch, with the requirement that the engineer responsible for any steel structure should give a certificate that the "steel used is of a quality possessing considerable toughness and ductility."

It will be seen from the foregoing that, with the exception of the instructions issued after the report of the Royal Commission in 1849, as to the "special provision in bridges under 40 feet span for the increased stress caused by a rapidly moving load," which have practically remained a dead letter, the Board of Trade has not issued any regulations with respect to the design of girders, other than those of cast iron, having regard to the extra stresses induced in bridges of moderate and small spans by the action of moving loads passing rapidly over such structures. The rules simply specify that "the heaviest locomotive, boiler-truck or travelling crane in use on the railway are to be taken as a measure of the load to which the girders of a bridge may be subjected."

It is of the highest importance that railway underbridges should now be designed of such strength that they may not become obsolete in a short time owing to augmented loads on them from increasing weights of locomotives, etc., or from an underestimation of the effects of moving loads upon them, as has been the case in the past. Owing to want of knowledge on the part of designers of the earlier railway bridges, enormous sums of money have been spent, and indeed are still being spent, by railway companies in Great Britain, on the Continent of Europe, in the United States of America, in Canada, and in India and Australia, in reconstructing numbers of girder underbridges which have been taken down and replaced by stronger structures, not from reasons of wear or decay, but simply because they are incapable of carrying with safety the modern heavy rolling loads. The Queensland Government are at the present time contemplating the expenditure of £366,000 for this purpose.

In estimating the moving loads on bridges of the spans under consideration it is sufficient to take into account the heaviest locomotives only; as, although there are a few boiler-trucks which if loaded to their fullest capacity are capable of bringing a somewhat greater load on the girders of bridges of certain spans than the locomotives would do, still, the occasions on which they are fully loaded are very few, their number is very limited, and they are free from the tendencies to increase the loads specified under heads (*c*) and (*d*), so that they may with safety be left out of consideration. The majority of boiler-trucks are distinctly inferior

to locomotives in their effect on the loading of bridges; and the heaviest travelling cranes are in all cases much lighter loads than locomotives.

The demand for higher speeds and the greater weight of passenger trains due to the conveniences and luxuries now provided for travellers, has led to greater power and weight in the locomotives; and it is evident that, in the heaviest and most recent locomotives of British railways, the limit of weight has been reached so far as their influence on the girders of underbridges is concerned. Any increase of weight of individual locomotives in the future, will, owing to the limitations of the loading gauge, be attended by a corresponding increase in length and in the number of wheels upon which the weight is carried, so that they will not impose any heavier loads on the bridges than the present heaviest types do. This being so, and having also in view the increased knowledge of the properties of materials, the present would seem to be a favourable time for reconsideration of the Board of Trade rules for the strength of underbridges, and for the issue of a Table of uniformly distributed moving loads for which bridges of various spans should be designed, making allowances for impact, etc. To these might be added rules for the allowable stress in the metal of the girders with varying coefficients or factors of safety, preferably using some modification of Wöhler's law, somewhat similar to the regulations issued by the French, Russian, and other continental governments, and by those of some of the United States of America.

With a view to obtain a comprehensive list of moving loads, the Author has worked out for forty locomotives which are (1898) the heaviest in use on the principal British railways, the equivalent uniformly distributed loads per lineal foot which include all stresses, for spans between 5 feet and 100 feet. Twenty-six of these locomotives, together with diagrams showing the equivalent uniformly distributed loads on the main girders and the concentrated loads on cross girders of varying distances apart, are shown in Plate 1, and the general data of these diagrams are given in tabular form in Tables I, II and III of the Appendix. These include the heaviest passenger, goods and tank locomotives in use on the railways mentioned. Twenty-four of the locomotives are those of leading English railways, one is a tank engine of the Caledonian Railway, and one is a passenger engine designed for the Belgian State Railways by Mr. J. F. Macintosh. The figures for fourteen other locomotives were worked out, but as they

proved to give lighter loads than those selected, they have not been plotted on the diagram or given in the Tables.

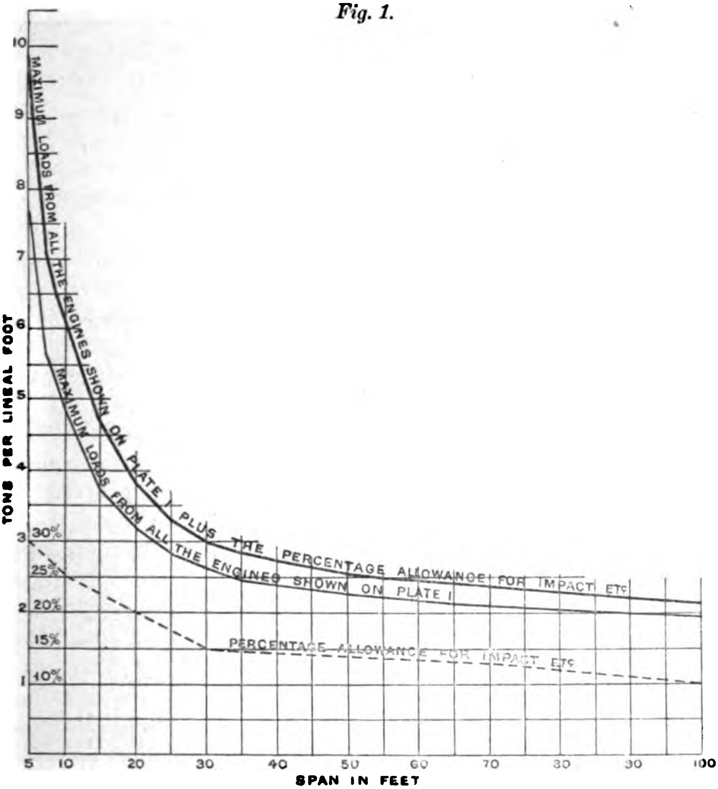
The equivalent uniformly distributed loads were obtained in the following manner for each locomotive. The span of 100 feet was covered with two, or more if necessary, of the locomotives under consideration, and from the reactions at the ends of the span and the weights on the axles, the bending moment at each wheel-position was calculated. The usual bending-moment diagram was plotted from the figures so obtained, and from this diagram the bending-moment diagrams for different positions of the locomotives on all the other spans were obtained by the graphic method. A number of positions for each span having been taken, and their bending-moment diagrams having been obtained and plotted, a parabola was drawn which would include all the diagrams, touching the extreme salient points of the diagrams, and from this parabola the equivalent uniformly distributed load was calculated.

The spans for which these calculations were made were 5 feet, 7 feet 6 inches, 10 feet, 15 feet, and each additional 5 feet up to 50 feet, 60 feet, 70 feet, 80 feet, and 100 feet. The line connecting these points on the diagram was drawn straight from point to point, and the loads for spans other than those mentioned above and given in Tables II and III, can be obtained by inspection from Plate 1. It will be seen from this Plate and Table II, in which the maximum is indicated for each span by a thick line underneath the figures, that the locomotive which causes the maximum load at one span does not do so at another span; and that a diagram showing the maximum loads due to all the twenty-six engines will be composed of loads from a number of them, *i.e.*, the Great Eastern passenger engine gives the maximum for the 5 feet span owing to its having the heaviest load on an axle, while for spans 7 feet 6 inches to 15 feet the Great Western goods engine, from 20 feet to 25 feet the Lancashire and Yorkshire tank engine, from 30 feet to 50 feet the Belgian State passenger engine, and from 60 feet to 100 feet the Great Northern tank engine, give the maximum load. The above remarks refer to the equivalent uniformly distributed loads for the main girders. For the concentrated loads on the cross girders, the Great Eastern passenger engine is again the heaviest at the shorter distances, viz., between 3 feet and 7 feet, for the reason already given; while for longer distances apart, viz., from 8 feet to 10 feet, the London and North Western goods engine gives the

maximum loads, owing to the concentrated wheel-base of this engine. The maxima so obtained are plotted in fine line on *Figs. 1* and 2, and are given in tabular form in Tables IV and V for main and cross girders respectively (see columns headed x).

The manner in which the stresses due to impact, and the other factors (a, b, c, and d) previously referred to, are to be determined and allowed for, is a point on which engineers hold different opinions. The allowance can be made in the following ways:—

Fig. 1.



(1) By increasing the given static loads by a percentage decreasing with the span.

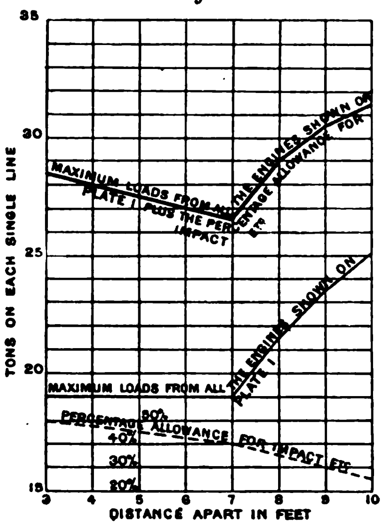
(2) By taking the loads and increasing the stresses due to them by varying percentages as before, using different percentages for the flanges and web.

(3) By taking the given static loads, and varying the working unit-stresses.

Whichever method is used, the amount to be allowed is necessarily largely empirical, and is based on the results of experience. Considered theoretically, a very large allowance would be necessary. Professor Melan[1] investigated analytically the effect of moving loads on metal bridges, and, after considering the question exhaustively, concluded that moving loads should be increased by percentages ranging from 80 per cent. for a span of 6 feet, to 30 per cent. for a span of 100 feet, in order to reduce them to an equivalent static or dead load.

The Author is of opinion that the method indicated in (1) is the best and simplest way of making the allowance for impact, &c.; and from numerous tests and observations of the deflections of the girders of underbridges under moving loads, he considers that the increase estimated on theoretical grounds by Professor Melan is excessive. He suggests that an allowance ranging from 30 per cent. at 5 feet span to 10 per cent. at 100 feet span will be sufficient for main girders; and for cross girders an allowance of 50 per cent. for girders 3 feet apart should be made, decreasing to 25 per cent. for those 10 feet apart. These percentage allowances are plotted in dotted line on *Figs. 1* and *2*, and are given in the columns headed y in Tables IV and V. The thick lines on these figures show the maximum loads due to all the locomotives, plus the percentage allowances for impact, &c.; and these the Author suggests should be used as a basis for calculating the strength of the girders of railway underbridges. Tables IV and V give, in the column headed z, similar information in a tabular form.

Fig. 2.



In conclusion, the Author desires to express his thanks to the chief locomotive engineers of the Great Eastern, Great Western,

[1] Zeitschrift des Oesterreichischen Ingenieur- und Architekten-Vereines, May, 1893, p. 293.

Great Northern, London and South Western, Midland and North Eastern Railways, and to Mr. J. A. F. Aspinall, M. Inst. C.E., of the Lancashire and Yorkshire Railway, for their courtesy in placing at his disposal the particulars as to the wheel-bases and weights of the locomotives, from which the information contained in the drawings and Tables has been prepared.

The Paper[1] is accompanied by two sheets of drawings, from which Plate 1 and the Figures in the text have been prepared.

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[1] Since the Paper was written, two heavy locomotives of quite new types have appeared; one a 10-wheeled 4-coupled passenger engine for the Lancashire and Yorkshire Railway, and the other a 10-wheeled 6-coupled passenger engine for the North Eastern Railway. Neither of these engines gives heavier loads than those plotted on the diagrams; the Lancashire and Yorkshire engine giving practically the same loads as the Great Northern 10-wheeled passenger engine, and the loads for the North Eastern engine being practically the same as for the engine of the Belgian State Railways.

[APPENDIX.

APPENDIX.

TABLE I.—WEIGHT OF HEAVIEST TYPES OF LOCOMOTIVES, 1898.

—	Belgian State Railways.	Caledonian Railway.	Great Eastern Railway.	Great Northern Railway.	Great Western Railway.	London and North Western Railway.	London and South Western Railway.	Lancashire and Yorkshire Railway.	Midland Railway.	North Eastern Railway.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
Passenger Engines.										
Total weight	104·27	..	84·35	98·90	84·65	80·50	87·00	70·92	85·48	91 90
Per lineal foot over all . .	1·82	..	1·58	1·71	1·47	1·56	1·59	1·40	1·61	1·62
„ „ „ wheel-base .	2·12	..	1·92	2·04	1·78	1·83	1·90	1·72	1·95	1·97
Maximum load on an axle .	17·96	..	19·00	16·00	17·05	17·40	16·20	16·50	18·50	18·70
Goods Engines.										
Total weight	..	..	69·55	77·90	93·00	75·85	78·80	68·25	76·46	75·65
Per lineal foot over all . .	..	..	1·47	1·54	1·61	1·46	1·50	1·40	1·54	1·51
„ „ „ wheel-base .	..	..	1·96	2·02	1·91	1·91	2·02	1·90	2·03	2·00
Maximum load on an axle .	..	..	14·40	15·90	16·55	14·40	16·00	15·00	13·65	15·50
Tank Engines.										
Total weight	..	53·80	58·61	60·80	47·00	52·30	54·65	59·15	51·02	55·22
Per lineal foot over all . .	..	1·60	1·68	1·70	1·55	1·56	1·56	1·53	1·53	1·54
„ „ „ wheel-base .	..	2·45	2·52	2·23	3·03	2·35	2·31	2·43	2·32	2·45
Maximum load on an axle .	..	17·54	15·29	17·10	15·77	15·50	18·00	17·40	16 75	16 58

The information contained in this Table is given in greater detail in Plate 1.

TABLE II. MAIN GIRDERS.—UNIFORMLY DISTRIBUTED LOADS IN TONS PER LINEAL FOOT OBTAINED FROM PARABOLAS WHICH INCLUDE ALL BENDING MOMENTS CAUSED BY THE ENGINES GIVEN IN TABLE I.

Spans.	Belgian State Railways.			Caledonian Railway.			Great Eastern Railway.			Great Northern Railway.			Great Western Railway.		
	Passenger.	Goods.	Tank.	Passenger.	Goods.	Tank.	Passenger.	Goods.	Tank.	Passenger.	Goods.	Tank.	Passenger.	Goods.	Tank.
Feet. 5·0	7·18	..	..	..	..	7·02	7·60	5·76	6·11	6·40	6·36	6·84	6·82	6·62	6·31
7·5	4·80	..	..	..	..	4·68	5·07	3·81	4·08	4·27	4·24	4·56	4·55	5·55	4·21
10·0	3·88	..	..	..	..	4·15	4·48	3·55	3·75	3·50	3·75	4·10	4·10	4·85	3·90
15·0	3·20	..	..	..	..	3·34	3·20	2·97	3·20	2·98	3·10	3·37	3·50	3·74	3·42
20·0	3·00	..	..	..	..	2·95	2·74	2·40	2·80	2·45	2·82	3·03	2·97	3·00	3·00
25·0	2·80	..	..	..	..	2·56	2·37	2·30	2·56	2·30	2·56	2·69	2·56	2·72	2·62
30·0	2·63	..	..	..	..	2·30	2·22	2·13	2·37	2·14	2·27	2·40	2·22	2·53	2·45
35·0	2·48	..	..	..	..	2·11	2·09	2·01	2·22	2·06	2·05	2·35	2·05	2·35	2·32
40·0	2·40	..	..	..	..	2·07	2·00	1·90	2·10	1·98	1·91	2·31	2·00	2·20	2·25
45·0	2·32	..	..	..	..	1·93	1·90	1·81	2·04	1·91	1·82	2·28	1·94	2·15	2·18
50·0	2·24	..	..	..	..	1·86	1·85	1·70	1·98	1·85	1·80	2·21	1·92	2·10	2·12
60·0	2·13	..	..	..	..	1·75	1·82	1·67	1·95	1·82	1·73	2·17	1·85	2·00	2·00
70·0	2·04	..	..	..	..	1·73	1·80	1·63	1·92	1·80	1·68	2·11	1·80	1·95	1·93
80·0	2·01	..	..	..	..	1·70	1·77	1·60	1·88	1·80	1·67	2·06	1·75	1·90	1·89
100·0	1·96	..	..	..	..	1·70	1·72	1·52	1·80	1·80	1·64	1·97	1·65	1·80	1·80

The above figures are plotted in Plate 1, the character of the thick line inside the driving wheels of the engine indicating the line on the diagram referring to it

The maximum load for each span is indicated by the figures underlined.

TABLE II. MAIN GIRDERS.—UNIFORMLY DISTRIBUTED LOADS IN TONS PER LINEAL FOOT OBTAINED FROM PARABOLAS WHICH INCLUDE ALL BENDING MOMENTS CAUSED BY THE ENGINES GIVEN IN TABLE I.—*Continued.*

Spans.	London and North Western Railway.			London and South Western Railway.			Lancashire and Yorkshire Railway.			Midland Railway.			North Eastern Railway.		
	Passenger.	Goods.	Tank.	Passenger.	Goods.	Tank.	Passenger.	Goods.	Tank.	Passenger.	Goods.	Tank.	Passenger.	Goods.	Tank.
Feet. 5·0	7·00	5·76	6·20	6·50	6·40	7·20	6·60	6·00	6·96	7 40	5·82	6·70	6·96	6·20	6·63
7·5	4·95	4·40	4·12	4·32	4·27	4·10	4·40	4·00	4·64	4·94	3·88	4·47	4 99	4·13	4·42
10·0	4·00	3 90	3·85	3·87	3·90	3·90	4·05	3·72	4·15	3·76	3·52	3·90	4·38	3·85	4·00
15·0	3·00	3·40	2·77	3 20	3 20	3·45	3·20	3 20	3·55	3·28	2·95	2·84	3·24	3·23	3·14
20·0	2·69	3·00	2·40	2·60	2·80	3·00	2·85	2·80	3·20	3·00	2·62	2·64	2·90	2 90	2·80
25·0	2·38	2·68	2·21	2·30	2·45	2·61	2·56	2·46	2·81	2·66	2·30	2·43	2·56	2·43	2·56
30·0	2·10	2·46	2·11	2·13	2·22	2·30	2·30	2·17	2·48	2·41	2·10	2·27	2·49	2·22	2·31
35·0	2·05	2·28	2·00	2·06	2·09	2·15	2·09	2·00	2·35	2·22	1·98	2·12	2 35	2·09	2·16
40·0	2·00	2·11	1·88	2·00	2·00	2·00	1·90	1·90	2·20	2·06	1·92	2·00	2·25	1·98	2·00
45·0	1·95	1·97	1·80	1·95	1·90	1·91	1·82	1·77	2·05	1·98	1 89	1·89	2·13	1 90	1·89
50·0	1·90	1·85	1·77	1·92	1·85	1·85	1·75	1·70	1·92	1·96	1·86	1·88	2·05	1·85	1·82
60 0	1·78	1·77	1·70	1·85	1·81	1·82	1·67	1·66	1·85	1·92	1·80	1 85	1·89	1·75	1·77
70·0	1·77	1·74	1·70	1·82	1·77	1·79	1·62	1·63	1·79	1·87	1·75	1·82	1·83	1·68	1·75
80·0	1·75	1·70	1·65	1·80	1·72	1·75	1·58	1·58	1·75	1·85	1·71	1 78	1·75	1·64	1·73
100·0	1·66	1·60	1·65	1·72	1·64	1·68	1·54	1·52	1·72	1 80	1·68	1·72	1·72	1 60	1·70

The above figures are plotted in Plate 1, the character of the thick line inside the driving wheels of the engine indicating the line on the diagram referring to it.

The maximum load for each span is indicated by the figures underlined.

TABLE III.—CROSS GIRDERS.—CONCENTRATED LOADS IN TONS ON EACH SINGLE LINE FROM ENGINES GIVEN IN TABLE I.

Distance Apart.	Belgian State Railways.			Caledonian Railway.			Great Eastern Railway.			Great Northern Railway.			Great Western Railway.		
	Passenger.	Goods.	Tank.	Passenger.	Goods.	Tank.	Passenger	Goods.	Tank.	Passenger.	Goods.	Tank.	Passenger.	Goods.	Tank.
Feet.															
3	17·96	..	..	..	..	17·54	19·00	14·40	15·29	16·00	15·90	17·10	17·05	16·55	15 77
4	17·96	..	..	..	..	17·54	19·00	14·40	15·29	16·00	15·90	17·10	17·05	16·55	15·77
5	17·96	..	..	..	..	17·54	19·00	14·40	15 29	16·00	15·90	17·10	17·05	16·55	15·77
6	17·96	..	..	..	..	17·54	19·00	14 40	15·29	16·00	15·90	17·10	17·05	16·79	15·77
7	17·96	..	..	..	..	17·54	19·00	14·40	15·29	16 88	15·90	18·71	17·05	18·25	15·77
8	20·51	..	..	..	..	18·48	19·75	15·10	16·24	19·84	15·90	19·91	17·97	20·77	17·24
9	22·52	..	..	..	..	20·64	20·50	17·20	18·30	21·91	17·89	22·18	18·97	22·70	19 99
10	24 12	..	..	..	..	22·35	22·70	19·50	21·00	23·57	19·59	24·40	21·30	24·75	22·71

Distance Apart.	London and North Western Railway.			London and South Western Railway.			Lancashire and Yorkshire Railway.			Midland Railway.			North Eastern Railway.		
	Passenger.	Goods.	Tank.	Passenger	Goods.	Tank.	Passenger.	Goods.	Tank.	Passenger.	Goods.	Tank.	Passenger.	Goods.	Tank.
Feet.															
3	17·40	14 40	15·50	16·20	16·00	18·00	16·50	15·00	17·40	18·50	14·55	16·75	18·70	15·50	16·58
4	17·40	14·40	15·50	16·20	16·00	18·00	16·50	15·00	17·40	18·50	14·55	16·75	18·70	15·50	16·58
5	17·40	14·40	15 50	16·20	16·00	18·00	16·50	15·00	17 40	18·50	14·55	16 75	18·70	15·50	16·58
6	17·40	15 45	15·50	16 20	16·00	18·00	16·50	15·00	17·40	18·50	14·55	16·75	18 70	15·50	16·58
7	17·40	18·90	15·50	16·20	16 00	18·00	16·50	15·00	17·40	18·50	14·55	16·75	18·70	15·50	16·58
8	18 33	21·50	16·65	17·38	17·28	19·00	16·97	15·43	17·60	19 30	17·01	16·75	18·96	16·11	16 58
9	19·32	23·50	19·06	18·60	19 44	20·66	18 34	17·51	19·68	20·44	19·24	18·85	21·00	17·70	18·96
10	20·67	25·11	21 33	20·74	21·16	22·41	20·30	19 97	22·40	22·31	21·01	21·01	22·99	20·05	21·51

The above figures are plotted in Plate 1, the character of the thick line inside the driving wheels of the engine indicating the line on the diagram referring to it. The maximum load for each spacing is indicated by the figures underlined.

TABLE IV.—MAIN GIRDERS.

x = Maximum uniformly distributed loads in tons per lineal foot from Table II, plotted in fine line on *Fig. 1*.
y = Suggested percentage allowance for impact and other factors (a, b, c, and d) plotted in dotted line on *Fig. 1*.
z = Suggested maximum uniformly distributed loads for use in calculating girders, plotted in thick line on *Fig. 1*.

$$z = x + y.$$

Spans.	x.	y.	z.
Feet.	Tons.	Per cent.	Tons.
5·0	7·60	30·00	9·88
7·5	5·55	27·50	7·07
10·0	4·85	25·00	6·06
15·0	3·74	22·50	4·58
20·0	3·20	20·00	3·84
25·0	2·81	17·50	3·30
30·0	2·63	15·00	3·01
35·0	2·48	14·75	2·84
40·0	2·40	14·50	2·75
45·0	2·32	14·25	2·65
50·0	2·24	14·00	2·55
60·0	2·17	13·50	2·46
70·0	2·11	13·00	2·38
80·0	2·06	12·00	2·30
90·0	2·01	11·00	2·23
100·0	1·97	10·00	2·16

TABLE V.—CROSS GIRDERS.

x = Maximum concentrated loads in tons on each single line from Table II, plotted in fine line on *Fig. 2*.
y = Suggested percentage allowance for impact and other factors (a, b, c, and d), plotted in dotted line on *Fig. 2*.
z = Suggested maximum concentrated loads for use in calculating girders, plotted in thick line on *Fig. 2*.

$$z = x + y.$$

Distance Apart.	x.	y.	z.
Feet.	Tons.	Per cent.	Tons.
3	19·00	50·0	28·50
4	19·00	47·5	28·03
5	19·00	45·0	27·55
6	19·00	42·5	27·08
7	19·00	40·0	26·60
8	21·50	35·0	29·02
9	23·50	30·0	30·55
10	25·11	25·0	31·39

(Paper No. 3183.)

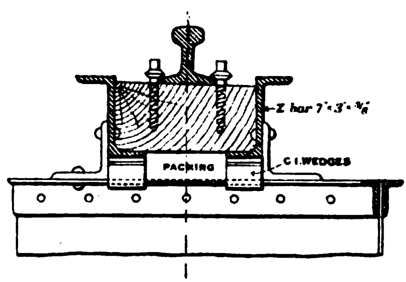
"Note on the Floor System of Girder Bridges."

By Charles Farquhar Findlay, M.A., M. Inst. C.E.

In carrying out a programme, now approaching completion, by which all the old girder bridges of the East Indian Railway were to be brought up to the standard of strength required for the loads and speeds now in use, a problem presented itself which is likely to occur elsewhere, and it is proposed to describe briefly how it was dealt with.

Among the numerous bridges on the main line of that railway there are two, consisting in the aggregate of twenty-six spans of 150 feet clear, and two consisting of twenty-six spans of 200 feet clear, all the spans being for single track. The main girders of these are of the close-latticed type of construction and are of adequate strength. The cross girders, however, are not strong enough to carry safely the engines which traverse the bridges, unless the axle-load of 15 tons is distributed over several cross girders by the longitudinal beams under the rails. The cross girders are spaced at intervals ranging in the different bridges from 3 feet 4 inches to 4 feet 6 inches. The main girders are spaced at distances ranging between 13 feet and 17 feet from centre to centre. Before the alterations in question were made, the longitudinal beams under the rails were of timber. It was considered doubtful how far timber beams varying in quality and age, and imperfectly continuous at the joints, could be relied on to distribute the load efficiently, and it was determined to replace them by steel beams of such strength as to reduce the load on each cross girder within a safe limit. Other remedies were considered, and were found to be open to many serious objections besides that of expense. The sketch in *Fig. 1* shows the system of construction adopted.

Fig. 1.

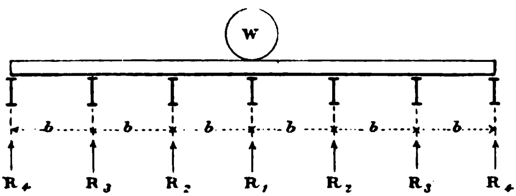


Cross Section of Longitudinal Rail-Bearer.

It was found that the cross girders varied in level in an irregular way and to an extent which required correction. This must have been the result of imperfect fitting at the time of construction. Folding wedges of cast iron were therefore interposed between the rail-bearer and the cross girder. These were carefully adjusted before the holes were drilled in the rail-bearers for attaching them by means of cleats to the cross girders. Unless this point had been attended to, the effect of the distributing beam might have been very different from what was intended. The effect of such beams in distributing the load may be calculated by assuming that the beam extends over a certain number of cross girders only, on each side of the load, and rests freely on each of these, the support given at each cross girder being proportional to the deflection at that girder. *Fig.* 2 represents the case as assumed.

In the particular case of one of the bridges above described (for which b = 40 inches) it was found that assuming the beam to rest

Fig. 2.



on five cross girders only, with the load, W, over the middle one, the reactions would be as follows:—

$$R_1 = 0 \cdot 45 \ W$$
$$R_2 = 0 \cdot 27 \ W$$
$$R_3 = 0 \cdot 005 \ W$$

Assuming the beam to rest on seven cross girders the reactions would be—

$$R_1 = 0 \cdot 44 \ W$$
$$R_2 = 0 \cdot 26 \ W$$
$$R_3 = 0 \cdot 05 \ W$$
$$R_4 = -\ 0 \cdot 03 \ W$$

These results appeared to show that sufficient accuracy was obtained without the more tedious calculations that would have been required in order to take account of the effect of cross girders still more remote from the load. If the load be supposed to lie

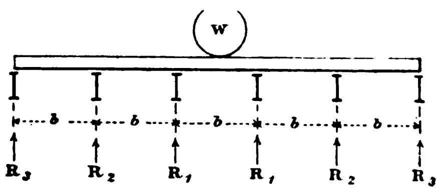
between two cross girders, as in the diagram shown in *Fig. 3*, and account be taken of six cross girders only, the distribution would be—

$$R_1 = 0 \cdot 36 \text{ W}$$
$$R_2 = 0 \cdot 19 \text{ W}$$
$$R_3 = -0 \cdot 05 \text{ W}.$$

For the maximum load on any cross girder, to the fraction of the axle-load immediately over it which it carries, must be added a portion of the next adjoining axle-loads. For the bridges above mentioned, the rail-bearer shown in *Fig. 1* reduces the static load on a single cross girder imposed by a six-wheeled engine weighing 45 tons, on a wheel-base of 15 feet, to 9 tons.

An approximate formula for the moment of inertia of a rail-

Fig. 3.



bearer which will reduce the load on a cross girder to any desired fraction of the axle-load immediately over that cross girder is—

$$I = \frac{3\, b^3}{64\, n^4\, a^3}\, I',$$

where—

I is the moment of inertia of each of a pair of rail-bearers;
I′ „ „ „ a cross girder;
b „ distance between cross girders, centre to centre;
a „ half span of the cross girder, supposed freely supported at its bearings;
n „ desired fraction,

$$= \frac{\text{Load on cross girder}}{\text{Axle-load supposed vertically over the cross girder}}.$$

This formula applies only to single-track bridges, and is arrived at (see Appendix) by assuming the rail-bearer to be of infinite length and continuously supported, the reaction (which may be upwards or downwards) being at every point proportional to the deflection. When the cross girders are as close together as in the cases described above, the results obtained on this assumption are

very near those obtained in the manner previously described. These calculations do not apply near the end of the span. Here the stringer may perhaps terminate, or in some bridges it may be continuous over the adjacent spans. In the former case it can be proved that the conditions in regard to uniform maximum loading on the cross girders will be approximately fulfilled if the end cross girder is made double the strength of the others, or if an extra cross girder similar to the others is inserted as near to the end of the span as possible.

There are, of course, many refinements which might be introduced in the theory, but for most purposes the methods of calculation described will suffice. The lattice type of construction seems to be coming into favour again, after having been discarded for a long period by many engineers in favour of simple triangulated types. The advantages claimed for the latter, in respect to the more definite determination of stress which they permit of, have, in the Author's opinion, been much exaggerated, and there are many cases in which the lattice girder is the most suitable type to use, having regard to economy, practical convenience and appearance. When lattice girders are used, a comparatively close spacing of cross girders often becomes imperative. The considerations advanced in this note may therefore be of service in regard to new bridges as well as in regard to the strengthening of old ones.

The work to which this Paper refers was designed by Mr. F. E. Robertson, C.I.E., M. Inst. C.E., late Chief Engineer of the East Indian Railway, and was mainly carried out under his direction.

The Paper is accompanied by tracings from which the Figures in the text have been prepared.

[APPENDIX.

APPENDIX.

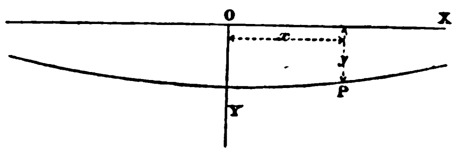
The approximate formula stated in the Paper may be established as follows:—

Consider the longitudinal stringer as a continuous beam of indefinite length, supported at uniform intervals by cross girders which are themselves elastic. The deflection of each cross girder, below the original plane of the unstrained floor, is the same as the deflection of the stringer at its point of attachment to that cross girder, and is proportional to the unknown load V upon the cross girder; or, in other words, is proportional to the vertical reaction $-V$ which takes effect upon the stringer at the same point.

Hence, in *Fig. 4*, where the bent stringer is supposed to carry a single load at O, if the ordinate y represents the deflection at any cross girder situated at the point P, the reaction at that point will be proportional to y. If the cross girders are placed at very short intervals the reactions will be distributed along the stringer, so that, on any short element $d\,x$ of its length the reaction will be proportional to $y\,d\,x$, and may be expressed by $k\,y\,d\,x$, where k is a constant.

Suppose the beam to carry a concentrated load W at O equal to one half of

Fig. 4.



the axle-load. If M be the bending moment and S the shearing force at any point P, whose co-ordinates are x and y, the conditions give—

$$d\,S = -\,k\,y\,d\,x,$$

from which $$\frac{d^2 M}{d\,x^2} = \frac{d\,S}{d\,x} = -\,k\,y.$$

Since $M = EI\dfrac{d^2 y}{d\,x^2}$ a differential equation to the curve of deflection is obtained—

$$\frac{d^4 y}{d\,x^4} = -\frac{k}{EI}\,y, \text{ or say } -c^4\,y.$$

The only solution of this equation consistent with the conditions is—

$$y = e^{-\frac{c x}{\sqrt{2}}}\left(A \cos\frac{c\,x}{\sqrt{2}} + B \sin\frac{c\,x}{\sqrt{2}}\right)$$

where A and B are arbitrary constants.

Since $\dfrac{d\,y}{d\,x} = 0$ when $x = 0$, $B = A$.

Since $\displaystyle\int_0^\infty k\,y\,d\,x = -\frac{W}{2}$ it follows that $A = \dfrac{c\,W}{2\sqrt{2}\,k}$ . . . . . . (I)

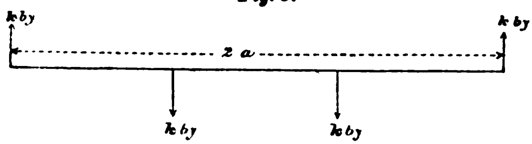
And the central deflection is A, because putting $x = 0$ in the above equation $y = A$.

If the line of deflection is constructed from this equation it is seen that the stringer bends in a sinuous curve, forming a series of waves, whose crests rise a little above the line O X, while their troughs lie below it, the deepest troughs being at O. But the waves die out rapidly as the distance x increases; and for practical purposes the line of deflection need only be traced for the space of a few cross girders to the right and left of the point O, covering the first wave-length. Beyond this the positive and negative ordinates are exceedingly small, and, consequently, the reactions may be neglected without sensible error.

Now consider the case of the cross girder of a single-track bridge freely supported at points whose distance apart is $2a$ (*Fig. 5*). If the distance b between successive cross girders is small, the case is that already assumed. The load on the cross girder at each rail is $V = k\,b\,y$, y being as before the deflection.

In practice the distance $2a$ is so large compared to the gauge of the rails that

Fig. 5.



the deflection at the rail does not differ appreciably from that at the middle of the cross girder, which is $\frac{V a^3}{3 E I'}$, I′ being the moment of inertia of the cross section of the cross girder, supposed uniform.

It follows therefore that—

$$y = \frac{a^3}{3 E I'} \times k\,b\,y,$$

or

$$kb = \frac{3 E I'}{a^3} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (II)$$

Let

$$n = \frac{\text{load on cross girder}}{2 W} = \frac{k b A}{W}.$$

By (I)

$$n = \frac{c\,b}{2\sqrt{2}},$$

$$\therefore n^4 = \frac{c^4 b^4}{64} = \frac{k\,b^4}{64 E I}.$$

By (II) this becomes

$$n^4 = \frac{3\,b^3 I'}{64\,a^3 I}$$

whence

$$I = \frac{3\,b^3}{64\,n^4 a^3} \times I'.$$

Discussion.

The PRESIDENT said he was sorry that neither of the Authors of the Papers was present. Mr. Farr was suffering from influenza, and had telegraphed that it was quite impossible for him to come from the country to attend the Meeting, and Mr. Findlay was in India. He thought the members would agree with him that the thanks of the Institution were due to the Authors for bringing forward, especially in the first of the two Papers, a question of some importance which he did not think had been previously discussed in the Institution, and which was certainly to a great extent lost sight of in the earlier days of bridge-construction—the question of the effect of impact resulting both from speed and also from the frequency of trains passing over bridges. The opinions given by Mr. Farr accorded fairly closely with his own experience. He had allowed of late years rather a larger margin of strength than the Author mentioned, but not to any very serious extent. It had to depend, of course, very much on the character of the rolling load and the frequency of the traffic, and engineers found in their experience abroad, where the rolling loads were different and the frequency of the trains much less, that they could safely allow a considerably less percentage for impact than in this country. He thought the discussion should prove a valuable one, and the Authors would be able to reply to it in writing. He begged leave to move a vote of thanks to the Authors of the two Papers. The President.

Professor W. C. UNWIN had read with much interest the first of the Papers. The Author had calculated, with very great labour, the exact bending-moment curves for no less than forty heavy locomotives; and, whether one agreed with all his calculations or not, it was a matter of great interest to engineers to have the bending-moment curves for those forty cases exactly determined. The conclusion at which the Author arrived was that, on the result of his calculations, there might be assigned an equivalent uniform load for bridges of any given span between 5 feet and 100 feet, and that a bridge might be calculated for that assigned uniform moving load. But it would surely seem very much simpler if, instead of assigning an equivalent uniform rolling load, a typical locomotive was selected, with less unequal loads and spacing, which would produce stresses at least as great as those due to any existing locomotive. That was the course which Prof. Unwin.

Prof. Unwin. had been taken under Government direction in France, and which was being taken by most of the bridge-building companies in America. It had the advantages—first, that once having assigned the typical locomotive for any given class of railway, bridges could be dealt with of any span; secondly, that the very convenient method which the Germans called "the method of the influence-curve" could be made use of; and thirdly, which he thought was a very great advantage indeed, it enabled the maximum shearing stresses, as well as the maximum bending moments, to be ascertained. The equivalent uniform rolling load threw no light upon the condition of the maximum shearing stresses. In America typical locomotives were assigned for the lightest class of railways, with loads of 11 tons on an axle, the axles being spaced uniformly 5 feet apart, and with 8 tons on the tender-axles, the axles being 8 feet apart: and for the heaviest class of railways with 19 tons on each axle, the axles being 5 feet apart, and something equivalent for the tender. It would be quite sufficient for the bridge-engineer to have it specified that he should build his bridge to carry two typical locomotives and a train of very heavy wagons on each line of way. The Author had alluded to the Board of Trade rules as to the limitation of the stresses in bridges, to 5 tons for wrought iron, and to 6½ tons for steel. He hoped that some time, when present troubles were over, there might be leisure enough to consider whether it was not a scandal that the only official rules in this country were rules which treated the whole load on the bridge as dead load, and which only limited the engineer to stresses which, in certain members of bridges, would be quite unsafe. He might recall some words which Sir Benjamin Baker had spoken 15 years ago, in a very interesting address to the British Association, when he said that the differences of strength in existing bridges were obvious to the educated eye, even without calculation, and that a bridge designed according to the Board of Trade rules would have to be strengthened by 5 per cent. in some parts, and by 60 per cent. in others, in order to be accepted either on a German railway or by any of the railway companies in the United States. He thought that now, after 15 years had elapsed and rolling loads were greater, Sir Benjamin Baker would have even to strengthen the statement he made then. It was not merely that the rules gave too great a margin of strength to some members of the bridge and would be unsafe for others: they were an obstruction in many ways to proper designing, and they had done much to prevent the adoption of any rational system of assigning the limits of

stress in bridges. The Author had alluded to some early experiments, which he said tended to show that loads moving at the speeds customary on railways were as destructive as dead loads of at least twice their amount. He imagined that the Author was referring to the experiments made in 1847 by the Railway Commission. Those were the only early experiments on which any such interpretation could be placed. The Commissioners had been appointed to consider the failure of the Dee Bridge when a train was going over it. They had early formed the impression that the failure of that bridge was due to some dynamical action, and they had made some very interesting experiments on that point. He thought there was a popular notion that those experiments did prove something like what the Author stated. It was only a popular impression, and it was an impression which had been exceedingly prejudicial in the consideration of the straining action in bridges. Not only was that not a conclusion that could be derived from the experiments, it was the opposite of the conclusion which had been obtained from these experiments by the Commissioners themselves. He would like to make that quite clear, because he thought those experiments had had a very prejudicial effect in bridge-designing. They were having an influence even at this moment on a point which he was coming to presently, and he would, therefore, speak of them a little more fully. The Commissioners had been obliged to make their experiments on a very small scale. They had employed chiefly cast-iron bars 9 feet in length and 1 or 2 inches square; and they had run a small truck at high speeds over those cast-iron bars and observed the deflections and the breaking weight. In these experiments the statical deflection due to the weights used had been usually 1 inch or $1\frac{1}{2}$ inch in 9 feet. The action of the truck at high speeds had been two-fold, the deflection had been three times the statical deflection, and the bar had broken down with one-third of the weight in the truck which it would have carried statically. At first sight those experiments seemed to show there was a very powerful influence, due to a weight travelling rapidly over a bar; but the bars used had been extremely flexible, and the maximum deflections of 5 inches which had been observed were deflections of one-twentieth of the span; whereas in railway bridges the deflection scarcely ever reached one-thousandth of the span. The results had been discussed with very great care by Professor Willis and Sir George Stokes, who had traced out perfectly the cause of the increase of deflection and decrease of strength. The action which they had observed was due to the fact that the bar had become so curved that the centrifugal action of the load and the kinetic energy of its

Prof. Unwin.

Prof. Unwin. exceedingly rapid deflection had increased the straining action at least three-fold in some of their experiments. Then they had proceeded to make some experiments on actual bridges, and the moment they had done so they had found the phenomena were very different. In the most carefully investigated case, the case of the Ewell bridge of 40 feet span, they had found, with a train running at 40 miles an hour over the bridge, that the increase of the deflection above that due to the same load at rest was only one-seventh. With their present knowledge, engineers would know that even that increase was due to causes of which the experimenters took no account. It was not due to the cause which produced the increased deflection of the very small and flexible bars. Their conclusion from their own experiments had been that the dynamical action of the load exhibited itself in a highly developed state, if the apparatus was on a small scale; but, with the large dimensions of real bridges, the effects of the centrifugal action were so greatly diminished that they were of comparatively small importance. That being the conclusion of the Commissioners, he thought it was erroneous to say that early experiments showed that the action of a load moving at speed over a girder produced effects equal to those of a dead load of twice the amount. There had been a tendency of late to say that in designing a bridge the maximum stresses due to the heaviest load in any position on the bridge had to be found, and to add to that an increased allowance for what was called impact or dynamical action. The Paper gave a good deal of countenance to that method of proceeding. He did not think the Author entirely adopted it, but most of the Paper was written as if that were the whole theory of calculating the dimensions of members of bridges. One distinguished American bridge-builder, Mr. Waddell, had distinctly said that he would discard altogether any attention to such things as Wöhler's law of the effect of the repetition of stresses, which he did not think applied to bridges at all. The only thing to be done was to calculate the maximum stress due to the typical heavy load, and to make an empirical allowance for dynamical action. But Professor Unwin thought that was the wrong view, and he would like to say a word further on that point. No doubt there was an action on bridges which might be called an action of impact, or a dynamical action, and, so far as he knew, the experiments which threw most light on that were some experiments, slightly alluded to in the Paper, by Professor Robinson and Mr. Turneaure[1] in the United States. These gentlemen had

[1] Transactions of the American Society of Civil Engineers, vol. xli. p. 410.

made a very large and very careful series of experiments on the deflections of girders of various spans, with recording deflectometers and recording extensometers on the members. They were exceedingly interesting experiments, and he did not think their results could possibly be ignored. The only thing about them as to which there was any doubt was whether the inherent difficulties of overcoming the effect of the inertia of the apparatus used were entirely overcome. If their conclusions were wrong, it was at any rate in the direction that the inertia of the apparatus made the apparent effects of dynamical action somewhat too great. In the first place these experimenters had found that the whole deflection of a bridge during the passage of a train might be divided into two parts. There was first the general deflection of the bridge, and secondly a vibration effect, the bridge swaying about its mean deflection curve. They had found that, so far as their experiments went, the deflection curve of the bridge, apart from the vibrations equally on either side of it, was not sensibly affected by the motion of the train, whatever the speed. So far from the mere fact of the train moving at speed over the bridge increasing the deflection, the general deflection curve had been unaffected, whatever the speed. On the other hand, of course the vibrations had increased very rapidly with the speed: they had been insignificant at speeds below 25 miles an hour, and had increased rapidly for speeds above that. Those vibrations had appeared to be due to three causes, of importance in the order in which he would mention them. The cause which had produced by far the greatest amount of vibration was the action of the unbalanced moving parts of the locomotive. In the second place, owing either to the rails not being exactly level or the two rails not being exactly on the same level, there had been centrifugal and lurching actions of the locomotive, which had tended to shift the load from one rail to the other in a periodic way; but that had produced very much smaller effects than the unbalanced parts of the locomotive. Thirdly, there had been the effect of the inequalities of the rail-ends, producing impacts or shocks, generally an unperiodic vibration. Everybody knew now that, somewhere about the year 1860, Wöhler had made some very interesting experiments, which had shown that, under repetition of loading, a bar broke down with loads sometimes less than half of the statical breaking weight, and in the form of Weyrauch and Launhardt's formulas, and other formulas of that kind, Wöhler's results had been very largely used in assigning the stresses of bridges. Some engineers said; "Well, when we adopt Wöhler's results in designing bridges we make our bridges too heavy, and so we will discard Prof. Unwin.

Prof. Unwin. them altogether." Others said Wöhler's results were due to dynamical action. Professor Unwin had carried out, under the direction of Sir William Fairbairn, nearly 40 years ago, the first experiment of that kind made; a well-known experiment on a wrought-iron girder, which was subjected to repetition of loading. He had since made a great many experiments, and he failed to see that the action, which might for shortness be called the Wöhler effect, was in any way due to dynamical action. If it were, there should be in the bars loaded and subjected to repetition of loading an increase of deflection or deformation, over that produced by the same load acting statically. He could not discover that there was any such increase of deformation, and if there was not, there could not be an increase of the actual stress. But further, he thought it was now clear—although it was quite certain Wöhler's law wanted further experimental investigation—in what direction the explanation of Wöhler's results had to be looked for. The explanation lay in the extraordinary variability of the position of the real elastic limit. When the stresses in either direction, compression or tension, exceeded certain limits, the elastic limit might be reduced even to zero stress by loads below what was commonly called the yield point. However that might be, the Wöhler effect was an effect which was not to be explained by dynamical action, and could not properly be taken into account by making an empirical allowance for the dynamical action of the train. After a study of the experiments made in Manchester on repetition of loading, he had come to the conclusion that the old rule referred to in the Paper, which the Board of Trade, as he thought without any particular insight or knowledge of what they were doing, laid down for cast-iron bridges, and one which, so far as he knew, had never been in any practical way acted on—the rule that a bridge should be calculated for its dead load and twice its live load—really fitted very well with the results of the experiments made at Manchester. About the year 1869 he had proposed that account should be taken of that effect of repetition of loading by designing bridges for the dead load plus twice the live load.[1] He did not think anybody had paid attention to that, but he was interested to see that in the very latest practice in the United States several of the large bridge-builders had come to the conclusion that that very simple rule really worked quite as well as the much more troublesome rule of Weyrauch and Launhardt. The stresses due to dead load plus twice the live load were of course not the real stresses in

[1] "Wrought-Iron Bridges and Roofs," p. 37. London: Spon, 1869.

the bridge, but the dead-load stresses equivalent to the actual stress; and for dead-load stresses it was safe to allow a limiting working-stress of 9 tons per square inch for steel. Of course that rule would not fit a few of the cases with which a bridge-builder had to deal, where the stresses reversed in direction; but for all other cases he could arrive at very nearly the same results by designing the bridge for a dead load plus twice the live load, as if the bridge had been designed for its whole load and then allowance made according to the Wöhler formula. If the common empirical and rather large allowance very often made for dynamical action of the train was adopted, and if, further, the stresses were limited by Wöhler's law, a bridge was undoubtedly obtained which was heavier than many bridges which were known to be doing their duty properly, and therefore some further investigation was wanted, because he really thought the way in which Wöhler's law had been applied to bridges had not been altogether a rational one. The dead-load-plus-twice-live-load rule appeared to provide margin enough both for repetition of loading and dynamical action. Prof. Unwin.

Mr. R. Elliott Cooper would confine himself to a few remarks upon the actual effect he had seen of different weights going across bridges at various speeds. He thought the first Paper was of great value, not merely on account of the information it gave to engineers interested in the subject, but also because it was likely to raise a valuable discussion. The information given as to the weights of the various locomotives in use on English railways, although of course only a matter of compilation, was really of considerable value, particularly to engineers who were engaged on the construction of railways in this country; because there was not ordinarily at hand information as to what actually were the weights to be dealt with on the different lines with which an engineer might be connected; and such information could only be obtained from the locomotive superintendents. He thought the Author had made one slight mistake in stating in Table I that the greatest weight on an axle of a Great Western passenger engine was 17·05 tons. He believed he was correct in saying that it was 19 tons, the same as that of the Great Eastern. The Author went upon the general idea that the load could be calculated as practically a uniform load. To do that in an ordinary bridge the cross girders must be distributing the load uniformly over the main girders. It was a very common custom 30 years ago to have what were called "distributing Mr. Cooper.

Mr. Cooper. girders"—small girders secured to the top of the cross girders in a double-line bridge, so as to distribute the load more evenly over the cross girders. At that time it was the fashion to make cross girders very much shallower than they were now. In a case of this kind an ordinary mode of construction would now be to put in a centre girder, so that the cross girders were made only half the length, or to have corrugated flooring. He merely mentioned that incidentally as one of the modes in which the difficulty was now got over. The question of the effect upon a bridge of the speed of the train passing over it, as distinguished from the effect of a dead load, was very important, and it seemed rather strange that the Board of Trade practically ignored this point altogether. He had been at a number of inspections, and he did not know a single case where any particular stress was laid upon the question as to whether the engines, two or three coupled together, should run at a high speed or should merely pass on to the bridge and there stand. The ordinary custom was simply to run slowly on to the centre of the bridge, and take the deflection, and then to run slowly off and see if the bridge had gone back. That, practically speaking, was the Board-of-Trade test. In many cases on lines in England he had tried the effect of passing over at various speeds up to about 20 miles an hour, and although there could be no doubt, as Professor Unwin had so clearly shown, that the effect upon a structure caused by the dynamical action of the train passing over at a high speed might actually be very destructive to the structure itself, the effect as registered by deflection was comparatively small. He had tried that on ordinary English bridges, notably on one that he built over the Trent, which had four spans of 120 feet. The total difference in the deflection caused by six locomotives, three coupled together on each road, when at rest over the centre of a span, and when running across the bridge ranged from $\frac{1}{8}$ inch to $\frac{3}{8}$ inch. About a year ago he had had occasion to report upon a railway in one of the colonies, and upon that railway there had been forty or fifty bridges designed and constructed in America, the largest of which had 180 feet span. The deflections in the case of those bridges had been practically the same with a standing as with a moving load, and they had been as follows. With 180 feet span curiously enough there had been no difference whatever—the deflection taken in that case with only one engine standing at the centre had been $\frac{3}{8}$ inch, and when running across at a speed between 15 and 20 miles an hour, which was the limit of speed in that colony, the

deflection had been the same. He might say that the bridges were typical American bridges, very deep in proportion to their span. With a span of 117 feet the difference had been $\frac{1}{8}$ inch, practically the same as the difference in the case of the Trent viaduct. For one with 100 feet span the difference had been also $\frac{1}{8}$ inch, and for a span of 75 feet the increase in deflection had been $\frac{5}{16}$ inch. For a span of 63 feet there had been no difference whatever, and he could not account for that; it seemed peculiar. The deflection had been $\frac{3}{8}$ inch, both with a standing load and when running over at any speed. In a viaduct having spans of 30 feet the difference in deflection had been $\frac{3}{16}$ inch. Those were the actual results he had found upon the bridges referred to. He had not then known what he had since learnt in regard to the great stiffness of American bridges, and he had expected to find that they were certainly weaker than the English bridges; but he had found that was not the case. With reference to the question that had been raised as to the Board of Trade laying down some rule, he thought he was correct in saying that the idea of the Board was not quite the same idea that prevailed on the Continent, where very strict autocratic rules were laid down and adhered to. The Board of Trade allowed a great deal of latitude, which might or might not be desirable, but which at any rate gave a certain amount of freedom to engineers. The Board practically took no responsibility provided the physical tests to which the structures were submitted came within certain limits which they had themselves laid down; although what those limits were he personally did not know, and he had never met anybody who did know. The Board-of-Trade inspector reported that he was satisfied with the structure, but how he was satisfied or why he was satisfied it was not for engineers to enquire. Mr. Cooper had been quite satisfied himself, and he was glad when he heard that the Board-of-Trade inspector was. He personally did not wish that any department should take out of the hands of engineers the responsibility which at present rested, to a very large extent, on them, and he thought that the restrictions in connection with signalling and other matters were sufficient for the purpose; although it would make the work of engineers undoubtedly much simpler if some rule were laid down to which everybody had to work, instead of leaving it to the individual opinion of each as to what he considered was the right rule to adopt. With reference to the second Paper, he did not think there was much to be said, although the title suggested a very wide scope. When he heard the title he thought that the point as to what was the best floor to adopt would form the essential part of the Paper, but that did not seem to be the Mr. Cooper.

Mr. Cooper. scope at all. The Author dealt chiefly with the question of the weakness of cross girders in structures already built, and how they could be strengthened. In connection with that he might mention that in the colony he had previously referred to, he found in every case that the greatest weakness in connection with the cross girders was the riveting up to the main girder. In that respect they were in many cases very weak. In nearly every instance, although the portion of the railway which had to be strengthened was built many years ago and for much lighter rolling stock, such a margin of safety had been given in the main girders by the engineer—who was a late eminent member of the Institution—that really it was sufficiently strong for the increased weight of locomotive that now had to be put upon the line. He thought that was a very satisfactory feature, and compared favourably with what the Author had said as to the enormous sum of £360,000 having to be spent for strengthening bridges in a colony which might almost be said to be in its infancy.

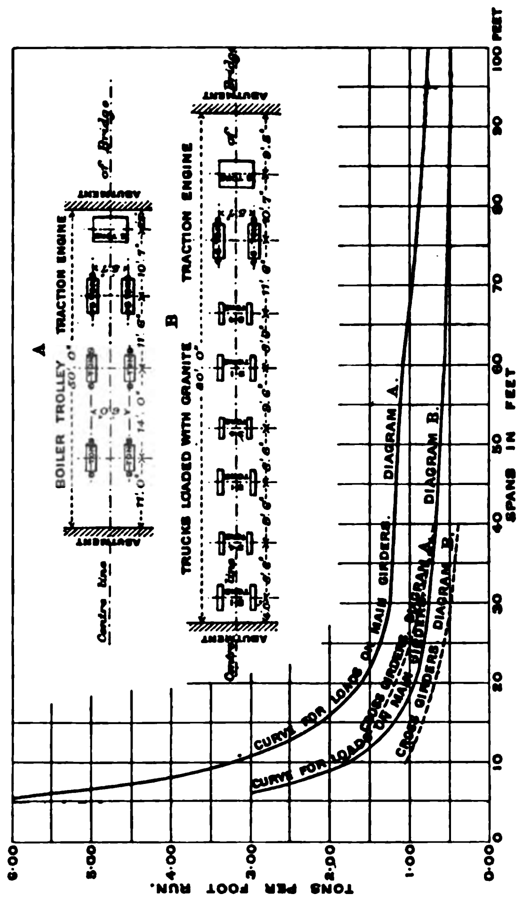
Mr. Inglis. Mr. J. C. Inglis said that Mr. Farr's Paper in itself was very interesting, and he had listened with great attention to the remarks which fell from Professor Unwin. To those who were as much concerned in the rebuilding of existing bridges as in building new structures, the questions with which Professor Unwin had been dealing were brought home in a very direct manner. In reading the Paper he had made a note of one point in particular on which he would like to get more reliable information, and that was the effect of impact upon main girders; because in dealing with the taking down and rebuilding of bridges designed many years ago by the late Mr. Brunel and other engineers, he was not aware of a single instance of a main girder, in which the stress was not more than 5 tons per square inch, having been removed on account of disintegration or loosening of rivets. The weakness had invariably developed in the rail-bearers and cross girders, particularly in the attachments of the latter to the main girders. His experience covered a rather extensive range, because he had had to deal with many branch lines constructed, unfortunately, under conditions which were not always of the best. The position into which the Board-of-Trade requirements had driven bridge-maintaining, as well as bridge-building, engineers induced them to make allowances by reducing the stresses in rail-bearers and cross girders as much as 57 per cent., leaving a working-stress of only 43 per cent. of what had been laid down by the Board of Trade, these allowances varying in different parts of the bridge-structure down to 4 per cent. The effect, therefore, was a process

of adjustment in order to secure a uniform life in the different Mr. Inglis. portions of a structure, and this was a result which had been arrived at in a way very different from the reasoning of Professor Unwin, but at the same time it seemed to bear out roughly the statement made by him. At any rate, he quite agreed with Professor Unwin that no case had really been made out for the general weakness in main girders where there was no stress greater than 5 tons to the square inch. That was one very important point. He thought, however, that it would be of immense advantage to railway engineers were a typical locomotive adopted by the Board of Trade, or by the Institution; and as the system described in the Paper was approximately that to which he had worked for spans up to 100 feet, he could say without hesitation that an agreed type of locomotive would not only create uniformity, but would also simplify the whole matter of bridge-designing. As an example of what an ordinary railway company had to do, he had looked up the records of the Great Western Railway Company, for which he was engineer, and found that, in 1885, when modern bridge-building on that railway might be said to have commenced, a Table of equivalent distributed moving loads, obtained from an officer of the Board of Trade, had been adopted, and this was followed for some years. In 1888 there had been an overhaul which had had the effect of adding 10 per cent. to the weight of the moving loads taken by the girders, and in 1893 a further increase of 10 per cent. had been made. Coming to the recommendations of the Author, he found that the company would have to add 36 per cent. in one case without impact, and 59 per cent. in the other; in other words, if the requirements of the Paper were carried out, it would cost his company alone a very considerable sum of money annually to meet them, a great deal of which would be expended in adding to the weight of main girders, for which as yet a case had not been made out. The Paper drew attention more than once to the great necessity for agitation by permanent-way engineers to reduce the oscillation of railway vehicles. There was a remark in it about the frequency with which two locomotives ran coupled together; and reference was made to the high speeds on English railways. He thought all connected with railways would agree with him that the more seldom two locomotives coupled together ran at high speed, the better it was for the permanent way. Each locomotive had its period of oscillation, and when those periods of oscillation coincided, there was a lurch, vertical or horizontal, against the permanent way. With regard to badly maintained permanent way, that was a point which did not escape attention, and he

Mr. Inglis. thought he might fairly say that great endeavours were now made to obviate the necessity for rail-joints anywhere near the centre of a girder. The use of long rails, and the placing of rail-joints comparatively near the abutments, further reduced that difficulty. He thought all engineers were alive to the fact that the worst that could be done to a bridge was to neglect to look very carefully after the permanent way upon it. He had had a good deal to do with strengthening structures, and the distribution of the load, as suggested in Mr. Findlay's Paper—but of course in different ways—had had a marvellous effect in increasing the life of some very large structures. He had no doubt that the greater attention now paid to the question of distributing the load had the effect of saving a great many structures; enabling them to go on longer than perhaps mathematically they could be considered capable of going. With regard to the insufficient balancing of locomotives, he was very interested to note the prominent position occupied by vibration among the three causes that had been mentioned. That was one reason why he looked forward with hope to the time when three-cylinder and four-cylinder locomotives would be used much more than the two-cylinder engine of to-day. It would be much better for the permanent way. He did not know whether any of the members had seen a pair of wheels put on to an axle and spun at a very high speed. It would naturally be thought there was no chance of vibration or of periodic oscillation, but he had been frequently undeceived on that point. At Swindon separate wheels and axles of a locomotive, apart from the driving-wheels, were generally balanced by adjusting them to run at a high speed without oscillation; and he thought, for fast running and luxurious travelling, especially on dining-cars, all wheels in the bogeys should be balanced and adjusted before they were put under the coach, because a wheel with a small oscillation might produce oscillation of the larger and heavier body of the coach above it. The question of balancing was, in his judgment, one of the first importance. The only other point which he would like to say a word about was perhaps a little beyond the scope of the Papers, and he mentioned it simply because it was a difficulty which he himself felt, viz., that comparatively little trouble was experienced in regard to underbridges, and more frequently the difficulty was in connection with over-bridges. The increased intelligence of County and Borough Councils, and kindred bodies resulted in railway companies being looked after much more closely. The earlier method had been somewhat empirical; an allowance was made per square foot—he

had had it up to 3 cwt. per square foot—but any effort which **Mr. Inglis.** would have the effect of establishing a practice in the way of providing loads for overbridges would be a great simplification and would save many meetings and many arguments. "The ordinary traffic of the district" was a phrase well known

Fig. 1.



EQUIVALENT MOVING LOADS FOR ROAD BRIDGES.

to those who had to deal with County or Borough Councils, and the more frequent use of steam road-rollers and traction-engines had altered the conditions of overbridges very much. In fact, traction-engines heavily laden had to be ranked as ordinary traffic, and the bridges built accordingly. In places like Wolverhampton and Birmingham it was a common experience to receive notice that

Mr. Inglis. a weight of 30 tons was to be taken over a bridge, and in one instance his company were asked to accommodate a casting which proved to be about 50 tons in weight. The diagram (*Fig. 1*) showed 32 tons drawn by a traction engine of 16 tons, with wheels placed in a definite position, and curves had been drawn representing equivalent distributed weights due to the moving load, where it passed along the centre of the roadway, and the increment due to that weight, by putting it close to the curb on one side or the other, gave the weight to be allowed for in the moving load on the main girder. This diagram might be reproduced, and would have at any rate the effect of ventilating the question. Numerous bridges had been built on those lines, and the assumption made was that not more than one road-roller or traction-engine would pass over the bridge at the same time, that was to say, that two would not meet on the bridge. Of course, it all came back to the question of £ *s. d.*; the additional steel which had to be put in the bridge to accommodate the two meeting on the same cross girder would be a serious item where thirty or forty bridges had to be built in the year.

Mr. Ross. Mr. ALEXANDER ROSS agreed very fully with the opening remarks of Professor Unwin, but thought he should also add that from a practical point of view it was an advantage to an office to have a Table of moving loads reduced to equivalent uniformly distributed static loads, such as suggested by Mr. Farr, for use in ordinary everyday work. He quite agreed that that Table might not give absolutely and mathematically correct results, but it was a great help in beginning to make the working-drawings of bridges. All who had to do with those things knew that the working-drawings of a bridge must be made by stages. First of all the assumptions had to be taken, and then they had to be worked out until the actual loads were applied and more definite and final results were obtained. The Table given by Mr. Farr and the facts he had adduced were, he considered, correct, except in the respect that the Author had taken the extreme loads to produce a Table, whereas in working locally an engineer might not get quite the highest factors, and therefore, in producing a diagram or Table for the loads he had to deal with himself he would probably get them much lower. But, having provided himself with such a Table, he had only arrived at one stage of the proceedings, as he had next to deal with the permanent load of the structure itself. He thought there was a great difficulty in adding to that Table in order to take into account the permanent load. The variations were so great that it was almost impossible to do so.

Mr. Ross.

After all was said and done, particular loads had to be applied to particular instances. He thought the Author had very fairly given the three rules which had been issued by the Board of Trade for the guidance of engineers. It was only in the first instance that they made any attempt at a distinction between the live load and the dead load. With regard to the second rule, having specified that the rule really implied a factor of safety of 4, it followed as a natural consequence that for steel a limiting stress of 6½ tons was also intended to be one-fourth, which would give 26 tons as the ultimate breaking stress. That was in 1877. He thought most of the members would agree that something more was known now of steel plates and angles, and that the figure of 6½ tons was very low. He considered 28 tons could be safely taken as the ultimate strength, and probably 30 tons. The Board of Trade were not bound to give a reason for anything they did, and possibly the lowness of "the limiting stress" was on account of the effect of various unknown stresses. He could not say whether that was so or not, but the general result was that if each more definite form of stress was taken and dealt with separately, in regarding and in determining the stresses the tendency was to give the benefit of the doubt in the direction of over-strengthening the bridges. But engineers had to do their work economically, and if the Board of Trade in the first instance gave a large margin on account of efficiency, another large margin were given in accordance with the Author's Table, and to that had to be added an amount for impact, etc., the effect would be that the bridges would be over strength. It all clearly proved that a Table approaching accuracy could not be prepared without taking all the elements of the case into consideration. As to impact, there was no doubt that it could be very much reduced, as the Author pointed out, by having a good road; but perhaps efforts to reduce impact were best applied not to the structure itself but to the locomotive. A locomotive with a bogey was very much less injurious to a bridge than one without a bogey. The bogey not only led the train on the track, but it also made the track by bringing everything to a bearing before the heavier weights behind came on. Locomotive engineers had always up to now sprung upon engineers weights, before their time, the locomotives taking the lead rather than the bridges; but he agreed with the Author in thinking that the former had attained their limit now, for they had almost reached the limit of the gauge. He considered that the present was an opportune moment for taking some definite steps in the matter. It was a question whether an Institution such as the Institution of Civil

Mr. Ross. Engineers should wait until the Board of Trade moved, or should take the experiments in hand themselves.

Mr. am Ende. Mr. MAX AM ENDE said that before he entered upon the discussion of the Paper on moving loads he would like to make a remark upon the second Paper. He had followed with interest the elegant mathematical deduction of the approximate formula given in the Appendix. Unfortunately, the Author did not give the two moments of inertia with which he had dealt in the principal part of the Paper, nor had he given the formula by which he arrived at the results. Mr. am Ende had been making calculations of the same sort, and he was able to state that the formula gave very good results, and might be used with advantage in preliminary calculations. The matter was of some importance in the case of trough-flooring, which did not distribute the load to any appreciable distance. With such flooring the question arose as to what were the stresses in the rail and in the troughs. The accurate values of R, in the case of *Fig. 2*, could easily be calculated from the following four equations, where the symbols were those stated in the Paper and where $2c$ was the distance between the rails:—

$$(R_1 - R_4)(a^3 - 3ac^2 + 2c^3)\,I = (27\,R_4 + 14\,R_3 + 4\,R_2)\,b^3\,I'$$
$$(R_1 - R_3)(a^3 - 3ac^2 + 2c^3)\,I = (14\,R_4 + 8\,R_3 + 2\cdot5\,R_2)\,b^3\,I'$$
$$(R_1 - R_2)(a^3 - 3ac^2 + 2c^3)\,I = (4\,R_4 + 2\cdot5\,R_3 + R_2)\,b^3\,I'$$
$$W = R_1 + 2\,R_2 + 2\,R_3 + 2\,R_4$$

These equations might also be used with a high degree of accuracy for double-line floors, if for $2c$ was put the distance between the two lines, viz., about 11 feet. The equations had been obtained by putting the deflections of the rail-bearer at seven points, expressed in terms of R, equal to the deflections of the seven cross girders. Mr. Farr's very suggestive Paper appeared to deal with two subjects; first, moving loads, and, secondly, a scheme for improving the Board of Trade rules. He might put that in another way, namely, first, forces acting on railway bridges, and, secondly, the calculation of sectional dimensions of the parts. The second subject was only generally indicated in the Paper; but the discussion had turned in that direction, and he would make a few remarks on the subject later on. The first paragraph in the Paper did not seem to be quite clear. The Author had said that distributed loads could not be used for the calculation of the moments in main girders if the cross girders were far apart, and at the top of the second page he said the same with regard to lattice and triangulated systems. Why should they not be used? Taking the parabola as the curve of moments

Mr. am Ende.

of a distributed load, the ordinates drawn through the cross girders were exactly the moments at those points. In the case of a lattice or triangulated system, the fulcrums of the forces in the top and bottom members had to be dealt with, and if the ordinates were drawn through the fulcrums and divided by the lever arms of the forces in the members, these forces would be found exactly. That extended so far that if irregular, concentrated loads were to be dealt with and the *funicular polygon* taken as the polygon of moments, even then, if the ordinates were drawn through the cross girders, they represented the exact moments at those points, and if a new polygon was drawn through the ends of the ordinates that polygon gave the exact moments at every point of the girder. By a very simple operation upon the *polygon of forces* it was possible to find the shearing forces also. There was so far no difficulty in the operations, and everything was clear. There was a difficulty only when the question arose what was at any point of a girder the *maximum* moment or the *maximum* shearing force. He believed it was Culmann [1] who had first used the funicular polygon as the polygon of moments, and had found the maximum moments tentatively by moving the span inside that polygon much in the same way as indicated in the Paper. Later writers, Winkler,[2] Fränkel,[3] Alexander,[4] Swain,[5] Johnson [6] and others, had tried to come nearer the solution of the problem, and by means of "curves of influence" and the discovery of certain relations between the position of the loads, and the maxima of moments and shearing forces, practical methods of dealing with the problem were established. Such methods, he thought, should be known to every British engineer, who had to deal with a variety of cases at home and abroad, in order to ascertain the moments and shearing forces accurately. The railway companies of England had mostly, he thought, applied such methods before they could set up tables of equivalent distributed loads, and the Board of Trade would expect such methods to be pursued, if it directed that *the greatest load that could be put upon a bridge should not produce more than* a stated stress upon the square inch. Other governments and railway companies had

[1] "Die graphische Statik." Zürich, 1866.

[2] "Theorie der Brücken," i, 5. Vienna, 1886.

[3] *Der Civilingenieur*, 1868, p. 271, and 1876, pp. 218, 441.

[4] "Analytical Theory of Bending Moments produced by travelling Load Systems." Tracts, 8vo, vol. 313, Library Inst. C.E.

[5] Transactions of the American Society of Civil Engineers, vol. xvii. p. 21.

[6] "The Theory and Practice of Modern Framed Structures." 7th Edition. New York, Wiley, 1899.

Mr. am Ende. also operated with such methods. The French Government rules of the year 1891 had given only a standard train, but the Austrian Government had taken the trouble not only to find out a standard train, but to calculate with great pains the accurate equivalent distributed loads, and those distributed loads for the bending moments were naturally different from those for the shearing forces. The German Government had done the same, but with more accuracy had given two parabolas whose apexes were at some distance from the middle. American companies had probably also done the same before they came to such simple rules as, for instance, that of the Pennsylvania Company, which directed that a moving load of 5000 lbs. per lineal foot should be taken, and, in addition, a single load of 50,000 lbs. in any position of the train. That seemed to be a very good rule, supposing it was correct in the sense that it embraced all cases, because the operation with those two loads was extremely simple. There were other railway companies in America which had adopted similar methods, *e.g.*, taking two loads at a distance of 50 feet apart instead of one. The Author mentioned several causes of the increase of the stresses through impact, &c., and his conclusions could not be widely differed from. With regard to the second part of the Paper, the calculation of sectional dimensions, he would mention that, in comparatively old times, when the Board-of-Trade rule required a limit of 5 tons per square inch (7·9 kilograms per square millimetre) under the heaviest possible load, in Prussia there was a rule with 7 kilograms per square millimetre, and in France with 6 kilograms per square millimetre, under standard trains. At the same time, the practice had prevailed in England, in America and elsewhere, that cross girders and hangers, and other parts subject to impact, &c., should be strained to a considerably less amount than the stated maximum. At that time Wöhler's law had been published. Wöhler's law was that besides the ordinary breaking strain a smaller strain, if often repeated, could produce fracture, and the differences of the stresses in those repetitions—in other words, the range of stress—gave a measure of the extent of the upper limit. A further and perhaps still more important discovery was that if the upper limit of the stress, alternating with zero, did not exceed the ordinary limit of elasticity, no amount of repetition could ever produce any change in the metal. Those discoveries produced a wave of enthusiasm on the Continent, not so much, he believed, because it was thought that the phenomena of stresses n a girder were directly comparable with the phenomena in the experiments, as because the formulas embodying Wöhler's law, such as

Mr. am Ende.

those by Launhardt and Weyrauch, seemed to express what every practical man had felt long ago and had acted upon, as already alluded to. Then opposition had been raised by Mohr, Laissle and Schübler, and a few others, who had attacked the logic of the conclusions, which led to a general and uniform adoption of the formulas for all parts of the bridge. The argument had been that if the dangerous limit of stress, above which fracture would occur sooner or later, and below which it would never occur, were for iron and steel—

$$s = e\left(1 + a\,\frac{\text{minimum S}}{\text{maximum S}}\right),$$

where e was the ordinary limit of elasticity in tons per square inch and a a number,[1] generally < 1, then $\frac{2\text{ maximum S}}{s}$ would be the sectional area in square inches of any member corresponding to a factor of safety of 2; and if, in consequence of additional forces and secondary stresses, minimum S as well as maximum S were increased by a uniform percentage the factor of safety would be uniformly reduced, the parts would be less, but uniformly remote from the dangerous limit and the general application of the formula would be logically correct. But in reality the increase was not an invariable function of $\frac{\text{minimum}}{\text{maximum}}$, but was irregular, and generally only maximum S was affected, except in parts subjected to alternate compression and tension; the margin of safety would therefore be reduced in some parts much more than in others, and the general application of the formula would not be logically correct. This had been the argument; it would thus be necessary to estimate the increase for each part of a bridge and to substitute new values for maximum S in the diagram of strains, before calculating the sectional dimensions with the formula. This might be done in any special case; but a general rule could only state average factors of increase, empirically arranged in groups according to the position of the parts and according to the dead weight of the bridge. Much, however, would be lost in point of accuracy by this empirical grouping, and the question would arise whether equally good results might not be attainable, either without the formula and with a number of empirical values for s arranged in groups, or with the formula in which a is a constant empirically determined so as to satisfy to some extent all cases and to render grouping dispensable. A

[1] $e = 14$ and $a = \frac{3}{4}$ corresponded to Phönix iron in Wöhler's Table X. "Über die Festigkeitsversuche mit Eisen und Stahl." Berlin, Ernst & Korn, 1870.

Mr. am Ende. rational derivation from Wöhler's law, however, could not be claimed for such a formula. The first plan had been adopted in the Austrian Government rules of 1887, in the German rules of 1895, and in some English specifications; the second plan in the specification of the Pennsylvania lines of 1897, with $a = 1$. In the French and Swiss rules of 1891 and 1892 respectively, the formula had been retained with $a = \frac{1}{2}$, *i.e.*, the "Launhardt-Weyrauch" formula.

It had been suggested that the Institution should take steps in order to improve the Board-of-Trade rules, and he thought, after the reading of the Paper and the discussion, the obvious suggestion for the next step was to have another Paper read which dealt more fully with the second part of the consideration, namely, the determination of the sectional area of the parts. Such a Paper should deal, he thought, not necessarily in much detail but broadly, with the following two questions. First, should the Board-of-Trade rule be interpreted literally, that was, in the sense that, all causes of increase considered, the stress per square inch should not exceed 5 tons—in which case the rule would insure a fairly equal factor of safety in all parts of a bridge; or was the enforcement of such a rule impracticable, and should it therefore contain a series of stress-coefficients instead of one to be applied to the usual diagrams of strains? Secondly, what determined the choice of the factor of safety? Was it the increase of the stresses by impact, etc., which was not usually taken into consideration? Was it the secondary and additional stresses which usually did not enter into the calculations? Or was it the necessity of covering faults in material, workmanship, erection and design? If it was all that together, could a fair estimate be made of these items, and would that lead to the conclusion that Wöhler's law should have a place in the calculation of bridges?

Mr. Dawson. Mr. W. Dawson stated that the heaviest travelling cranes were not in all cases much lighter loads than locomotives. A few weeks previously he had had occasion to renew the superstructure of one of the bridges on the Chester and Holyhead line, which was under his charge. The bridge consisted of four main girders, each 70 feet long and weighing about 30 tons; and, as the traffic over it was very heavy, amounting to something between two hundred and two hundred and forty trains per day on a weekday and about fifty trains on a Sunday, it had been necessary to consider the question of the best method of getting the old girders out of the way and of putting the new steel girders in their place. After some consideration, he had arranged to place a 20-ton crane at one end of each of the main girders and two 10-ton cranes, one on each line, at the

other end. The weight of the 20-ton crane had made him somewhat uneasy. He had not had the particulars of that crane, but he had had particulars of a similar steam-crane made to lift 20 tons, from which he had found that the weight of the crane was exactly 50 tons, carried on three axles having a wheel-base of 10 feet 6 inches; in other words, the weight of the 20-ton crane per lineal foot was no less than 5 tons or thereabouts. This weight was distributed in the following manner: 8 tons on the axle nearest to the jib, 17 tons on the middle axle, and 25 tons on the axle farthest from the jib, that was, the balance-weight end of the crane. Those weights, of course, were very much in excess of anything that had to be dealt with in the Papers, and he thought 25 tons alone on one axle was sufficient to cause some anxiety to the permanent-way engineer who happened to have charge of the line over which the crane was run. Most cranes, as was well known, were designed to carry a certain weight, and when they were being used for the maximum weight they were in a state of more or less unstable equilibrium. It was generally found that when a crane was lifting its heaviest weight, the far wheels (the wheels underneath the balance-weight), began to rise off the line. He had had considerable experience of cranes for lifting, and had taken special precautions to prevent the crane toppling over. In a case of that kind the weight on the front wheels of the crane must be something very great indeed, because it might almost amount to the weight of the crane itself, as well as the load it was lifting. Assuming the crane itself to weigh 50 tons (which in that case it did), and to lift 20 tons, there was a weight of 70 tons on the fore part of the crane, which was a very serious item. Supposing that crane was being used on a bridge of three spans, and its weight was on the middle span, it was difficult to say what effect it would have on the girder which was sustaining the crane. With the increased speeds and weights of trains and the larger number of trains run, it was not at all unlikely, he thought, that heavy steam-cranes would come into much more general use than at present, and, therefore, the weights should form an element for consideration whenever it was proposed to adopt them. It had been suggested by Mr. Farr that certain percentages should be added to the weights per lineal foot to counteract the effect of impact, etc. Mr. Dawson thought allowances could not be adopted in a general sense, because so much depended, it seemed to him, on the design of the bridge under consideration. For instance, in a girder bridge carrying two lines of rails, and consisting of two main girders only with cross girders the full width of the bridge, the girders would only be subjected to the

Mr. Dawson.

Mr. Dawson. limiting stress at very rare intervals, because it was not possible to get the maximum load on the bridge except with two trains (travelling in opposite directions), on the up and down lines, and with the heaviest axles of those engines simultaneously on or about the middle of the main girder. That seemed to him to be a very rare contingency, and the factor of safety of 4 which was usually adopted in bridges would probably cover it, because, speaking generally, the bridge would only be stressed to about two-thirds of what it had been designed to carry in the ordinary way. If the case of a bridge was taken where there was one girder carrying each rail—a very common case—then that bridge might be subjected to the maximum stress for which it had been designed every time a train passed over, which might happen a hundred times a day. That seemed to him to be a case where the question should be considered in regard to an increased percentage for impact.

Mr. Yeatman. Mr. M. E. Yeatman was interested in Mr. Farr's diagrams of uniform loads because they were very similar to some which he had worked out for an American railway a few years ago. But there was one important point of difference, and that was in the method of defining the equivalent uniform load. The Author had taken the uniform load as one which would produce a moment-parabola enveloping and including all the bending moments given in every position by the actual load. Of course that was a very safe way of covering everything that could possibly occur; but it seemed to him that it was hardly a rational one to take for general use, because it was liable to give at the centre of the span a very considerably higher moment than was produced by any of the actual loads or combinations of loads. He had adopted for the equivalent uniform load one which would produce at the centre of the span a bending moment equal to the greatest bending moment which could be produced at any point of the span by the actual loads. That seemed to him a more rational equivalent to take, because the maximum bending moment which could be produced by the actual loads was what had to be provided for. It might not occur exactly at the centre of the span. If it were produced by any even number of concentrated loads unsymmetrically disposed, it would not be exactly at the centre of the span, but it could never be very far away from the centre; and if a plate girder with parallel flanges was made of sufficient section at the centre of the span, the full flange-section would run far enough from the centre to cover the point at which the actual maximum moment occurred; and although there might be some

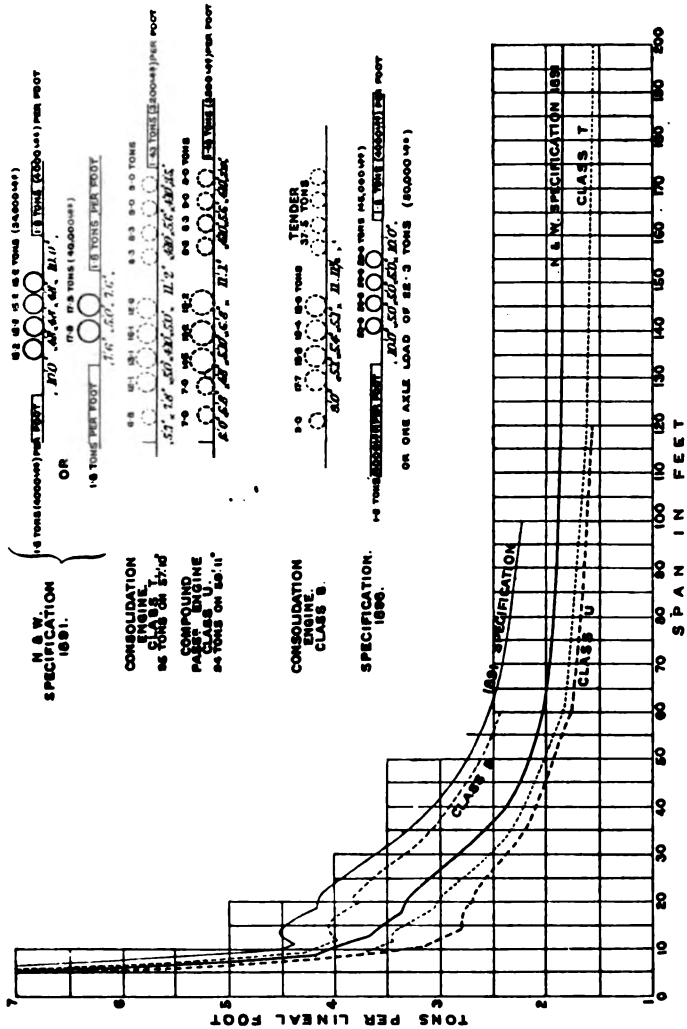
points at which the curve of actual moments would fall outside the parabola drawn from the equivalent load, it would be very easy to cover all those by making each cover-plate that stopped short of the end of the girder slightly longer than its theoretical length by the parabola of moments. That was, he thought, what was generally done in designing plate girders. In that case the requirements were easily met. In the other case, adopting the equivalent load suggested by Mr. Farr, an unnecessarily higher bending moment was reckoned at the centre than was actually obtained, leading to the adoption of an unnecessarily thick section in the centre. This would involve either putting on thicker plates than would be otherwise required, or possibly putting on an extra plate; which was certainly a disadvantage, both in the actual construction of the girder and in adding extra useless weight at the point where it did most harm. The greatest difference between the two methods would occur in the case of spans that were not quite long enough to take three loads, such spans as 7½ feet, 10 feet, or 12 feet. In that case the maximum moment at the centre would very likely be produced by a single load. It might possibly be produced to one side of the centre by two loads. If so, it would not be very much greater than that due to the one load at the centre; and the equivalent moment given by the Author's rule, which was arranged so as to cover the moments produced by the two loads near the quarters of the girder, would give a much greater moment at the centre. He had first noticed that point in seeing what a high equivalent load for a 10-foot span, for instance, the Author obtained from his Great Western goods engines as compared with the moments Mr. Yeatman had for a 10-foot span with much heavier engines. That engine—taking it from the cross-girder loads only—had about 16·55 tons on an axle, and the Author made his equivalent for moments on a 10-foot span 4·85 tons. The equivalent which gave the same actual maximum moment, Mr. Yeatman made to be 3·24 tons instead of 4·85 tons, on a 10-foot span. On a 7-foot 6-inch span he made it 4·41 tons instead of 5·55 tons. If that rule were adopted, the Author's absolute maximum for a 10-foot span would be that derived from the Great Eastern passenger engine, 4·48 instead of 4·85, which was a very large percentage of difference. There was another point to be noticed, viz., that if the system he had suggested, of taking the equivalent load as the load which would produce the actual maximum bending moment at or near the centre of the span, was adopted, there was no need to have a separate diagram for the floor-

Mr. Yeatman.

Mr. Yeatman. beam loads. The very same difference which gave, for instance, the maximum moment at the centre of the 20-foot span would give the maximum load upon the floor-beam spaced at distances of 10 feet from two other floor-beams. Between the two outside floor-beams there was a span of 20 feet and another floor-beam in the middle of that span; and the same equation of condition which would give the maximum bending moment in the middle of the 20-foot span would give the maximum for the load on the middle floor-beam. That being the case, the one diagram of equivalent moments was all that was wanted. To get the maximum load on floor-beams 10 feet apart, it was only necessary to look for the equivalent of 20-foot spans and multiply that equivalent by 10 feet: if 15 feet apart, it was necessary to take the equivalent for 30 feet and multiply it by 15 feet, which gave the floor-beam load. He had prepared diagrams on the system referred to, which were contributed in 1892 and 1894 to the American Society of Civil Engineers. They were drawn to a scale of thousands of pounds, and, as this made it rather difficult to compare them with the Author's diagrams, he had retraced them and drawn the scale in tons (*Fig. 2*). At the time he had prepared them it had been usual in American bridge-specifications to adopt, in prescribing a bridge-load, some actual engine, or at any rate some typical engine and tender, with a number of generally unequal, and sometimes very fractional, spacings between the wheels, with different loads upon them all. As a rule, the bridge-load was assumed to be made up of two such engines followed by a uniform train load, and the calculations for such a system became rather complicated. What was required was to see whether it was not possible to put in the specification a much simpler loading. At first it had been thought that such a loading as Mr. Max am Ende had mentioned might be adopted, viz., a large uniform load sufficient to cover any heavy train, with one concentrated load at the head or at the middle of it. That could be made to answer very well for the bending moments, but the same equivalent loads would not give the right thing for the shear. If the loads were taken so as to give the shear correctly they would give too much for the bending moment. For that purpose a diagram had been worked out for equivalent uniform loads for shearing, and equivalent uniform loads for bending moments. It had not been possible to find a load with a single concentration that would give a fair substitute for all, but it had been found possible to do it perfectly well by having four loads corresponding to the four loaded axles of heavy goods engines, and treating all

the rest as a uniform load. There was no need to take concentrations of tender-loads, as the tender-loads were not greater than the car-axle loads; and those four concentrated loads, either Mr. Yeatman.

Fig. 9.



followed or both followed and preceded by uniform loads at a specified distance, gave a diagram which followed the other very closely both for the bending and for the shear. Such an equivalent was taken as gave an excess of about 8 per cent. or

Mr. Yeatman. 10 per cent. above the heaviest engine, and that was adopted as the specification-load. A rather interesting point came up in connection with the enormous increase in rolling loads. In the year 1881 bridges were being designed for engines with four coupled axles, each having 22,000 lbs. on it. In 1891, the occasion he was speaking of, when the specification was adopted, there had been four axles, 4 feet 8 inches apart, with 34,000 lbs. on each, which had covered, with an excess of about 10 per cent., all the goods and passenger engines then in use. But in the year 1898 a new engine had been ordered for the road which had far exceeded that, and in order to cover it a new specification had had to be adopted which provided for four loads of 45,000 lbs., or about 19 tons, each, on four axles, spaced about 5 feet apart. That probably was in excess of anything in use on English railways at present; in fact the Author showed 19 tons as his biggest load on a single driving axle. In the case he was speaking of, 19 tons had been provided for on each of the four driving axles, and even with that his diagram of 10-foot span fell below what the Author showed. He thought the Author's figures were unnecessarily high. He would not say much on the second part of the Paper, but he might mention that American practice for a good many years past had been in favour of allowing in some way a considerable difference for live loads and dead loads. His practice was to use the Launhardt formula, the uniform load multiplied by $1 + \frac{\text{minimum}}{\text{maximum}}$; though, on the ground that the bridges were never intended to be strained above the limit of elasticity and that those effects of repeated stress did not come into play when the limit of elasticity was not exceeded, that formula had been somewhat discredited of late. But even if its actual derivation was shown to be not exactly logical, he still thought it was a very good way of representing the effects of the live loads. It practically covered the impact in a very satisfactory way. Some engineers, reacting from that formula, and also wishing for one simpler in application, merely doubled the live load. That method, he believed, was not at all new; in fact, Rankine gave it in his book, and the Board of Trade acknowledged it for cast-iron girders, although they did not seem to do so for wrought iron. Of course the whole idea of allowing more for a live load had long been acknowledged. He thought the very first acquaintance he made with bridge-calculations was in a little book by Sir Benjamin Baker,[1] which had an

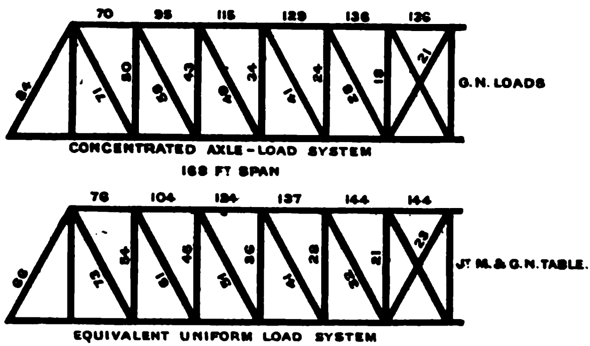
[1] "Long-span Railway Bridges." London, Spon, 1873.

Appendix on short-span bridges, and which showed that not only were the actual loads per foot much greater in short spans, but that it was necessary to allow a less stress per square inch in short spans than in long ones, and Wöhler's actual results showed the reason for that. At present in America the practice oscillated between doubling the live load and using the formula $1 + \frac{\text{minimum}}{\text{maximum}}$. There was the peculiarity that if 8 tons were taken for all dead loads—in America 15,000 lbs. were allowed for iron and 20 per cent. more for steel, which gave 18,000 lbs., or practically 8 tons—whichever formula was used, exactly 4 tons was obtained for all live load: but in intermediate stages, half live load and half dead load, the results were different. He had compared them, and the diagram would show that although in America they went as high as 8 tons for all dead load, yet in most bridges the Board-of-Trade allowance for steel would not be exceeded. With a live load equal to the dead load the method of doubling the live load would allow 5·3 tons, and the formula $1 + \frac{\text{minimum}}{\text{maximum}}$ would allow 6 tons. If the live load were twice the dead load it would be 4·8 tons and 5·3 tons respectively; and if the live load were 4 times the dead load it would be 4·4 tons and 4·8 tons respectively. With a ratio of 10 to 1 it would be 4·2 tons and 4·36 tons respectively; practically, therefore, for all spans from 500 feet down to very short ones, it would come within 6 tons per square inch, whichever formula was used. The experience in America with the maximum and minimum formula gave very satisfactory results. Mr. Yeatman.

Mr. T. G. Gribble thought the Papers were of great value as was the discussion also, in assisting the standardization of British bridge-practice, a thing which was very much needed if British engineers were to compete with foreign and colonial engineers. The suggestion had been thrown out that the Institution might do something towards improving the Board of Trade rules, and he thought it would also be of very great value if the Institution could see its way to have a Commission formed to standardize specifications in the same way as was done in America for general bridge-detailing, and so, to some extent, bring about uniformity where there were unnecessary variations, not only in style, which was inevitable, but in elementary methods of procedure and bases of calculation. Mr. Farr had attempted to give a Table that would cover the locomotives of all the English railways. Mr. Gribble did not quite know why he had included the Belgian Mr. Gribble.

Mr. Gribble. State Railway, unless he had sanguine expectations of the construction of the Channel Tunnel to bring the engines across; but at any rate as regarded British railways the Author's compilation was of great value, not so much from its having any finality, which it could not have, but because it was up to date. There were so many joint lines in this country and such wide running-powers, that it became the objective of bridge-practice to be able to carry any engine of any company. He thought one thing had been clearly shown by Mr. Farr's Paper, viz., that no company in this country differed so widely from other companies that, if an adequate Table could be formed economically to meet the needs of its locomotives, that Table could not also be made to meet the needs of other companies. But the question arose whether the Table was not wasteful on the one

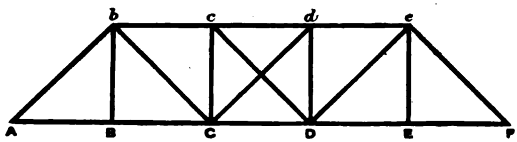
Figs. 3.



hand or inadequate on the other, and he had placed on the wall an illustration of the application of the two systems to a girder of 168 feet span (*Figs. 3*). As Mr. Max am Ende had remarked, the Author did not think the system was applicable to girders with open webs, but he dismissed that point in a very brief way and did not prove it. If therefore the Table could be shown to be applicable to open-webbed girders, it was *à fortiori*, applicable to plate girders. The diagram, *Figs. 3*, illustrated the divergence that occurred in actual practice between two entirely independent calculations of the same girder; the only common basis of calculation being a type drawing of all the engines in use upon a certain system. There was an initial difference in the maximum possible loading amounting to 2 tons in the end shears; and if that were eliminated, it would be seen that the stresses in corresponding members agreed fairly well throughout. At any rate, he

thought it was apparent that there was no extravagance in Mr. Gribble. that instance—the concentrated loads being covered in every case, with a slight excess. The margin was certainly not a greater one than was found in the diverse treatment of the Wöhler formulas by French and English authorities. *Fig. 4* and the accompanying Table illustrated another similar case of a shorter span. With regard to the way in which the Table of equivalent uniformly distributed loads was computed, no doubt the Author was quite correct in his principle of the enveloping parabola; but his results for short spans had been called somewhat in question, and Mr. Gribble would like to give a comparison

Fig. 4.



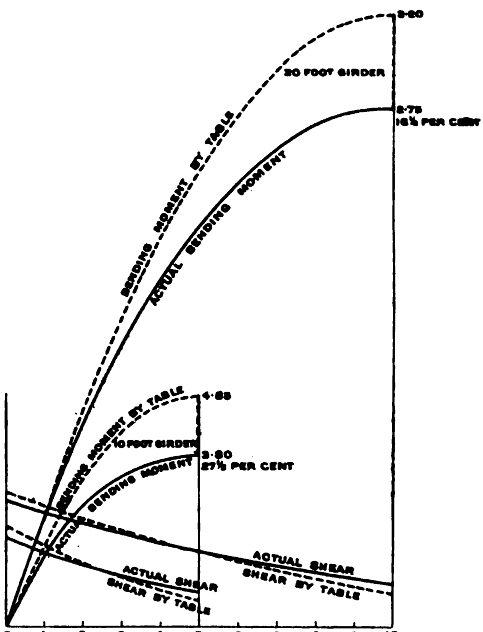
Member.	Axle Concentration.	Midland & Great Northern Table.	Great Central Table.
A B & B C	− 57	− 61	− 59
C D	− 81	− 92	− 89
b c	+ 82	+ 92	+ 89
c d	+ 82	+ 92	+ 89
A *b*	+ 80	+ 86	+ 84
B *b*	− 34	− 48	− 48
C *c*	+ 15	+ 22	+ 22
b C	+ 4 − 44	+ 14 − 54	+ 14 − 54
c D	− 28	− 32	− 32

between the Table of the Great Central Railway[1] and the Author's Table. On comparing the two it would be seen that in the 100-foot span there was only 8 per cent. less in the Great Central Table. In the 15-foot span, the Author's Table was 22 per cent. in excess, but Mr. Gribble thought it was not quite rational to take those very heavy loads for the short spans, because the Author thereby assumed that the flange was reduced

[1] *Engineering*, 8 Sept. 1899, p. 295.

Mr. Gribble. in the ordinary way of a girder of uniform strength, whereas short girders were always made of uniform section. The flange was the same throughout, and therefore if the maximum bending moment was taken, and the flange was calculated therefrom it was good enough for the whole girder. That rule, certainly as applied to longitudinals, held good for spans up to 30 feet. In Mr. Morison's great bridge over the Mississippi there were 30-foot longitudinals, but they were all of the same section throughout. In main girders the flange-section was reduced, but there was always an irreducible

Fig. 5.



minimum of flange-area, extending right through to the end of the girder, which had to be taken into account. If that were done he thought it would be found that the Great Central Table was nearer the mark, even if it were meant to be applied to all English railways, than the Author's Table. The waste of flange-material resulting from the use of the latter was illustrated for girders of 10 feet and 20 feet span, respectively, by the areas between the dotted and full lines in *Fig. 5.* The simplest way to standardize moving loads in this country would

Mr. Gribble.

be to publish annually a diagram of bending moment, end shear and centre shear covering all companies' loads; but a dual classification for main and branch lines might be worth consideration.[1] He thought it was more rational to allow for impact by reducing the working-stresses than by adding to the live load, because, as had already been remarked, the ratio of minimum to maximum stresses did not vary according to the span, but according to the construction of the girder. With regard to the theory of impact in rapidly moving loads, there had been much controversy as to whether the action was "fatigue of material" or "hammering." It was not demonstrable from experience, however, that either theory was correct. Old wrought-iron girders did not show a decrease of the modulus of elasticity, or in other words an increased deflection, unless from defective riveting. Neither did loads at ordinary train-speeds deflect the girders appreciably more than stationary loads. It had yet to be proved that laboratory experiments were chronometers of the life of actual girders. He had compared a pair of girders 20 years old made of wrought iron; the one was an open-webbed girder of 79 feet span and 15½ feet deep; the other was a short and very shallow plate girder with rounded ends, having a span of 27 feet and a depth of 2¼ feet. In both cases the deflection was about ¼ inch under ordinary train-loads, and had remained so, as far as could be judged. The traffic upon the bridges was very much greater now than at first; but calculating the actual flange-stresses from the dead load, and then computing the live-load stress within certain limits from the actual deflection, it appeared that those girders had never been stressed, and were not now stressed, through the ordinary running beyond something between 2 tons and 3 tons per square inch. Mr. Inglis had said that he never knew a main girder fail that was calculated to stand stresses up to 5 tons per square inch, and Mr. Gribble did not suppose anybody else had. But it was to be remembered that although the girders might be calculated to stand 5 tons per square inch, they probably did not get anything like that stress upon them under the ordinary working of the traffic. Then it was said that assumptions should be made for higher and higher loads, partly because engines were made heavier and partly because steel corroded more quickly than

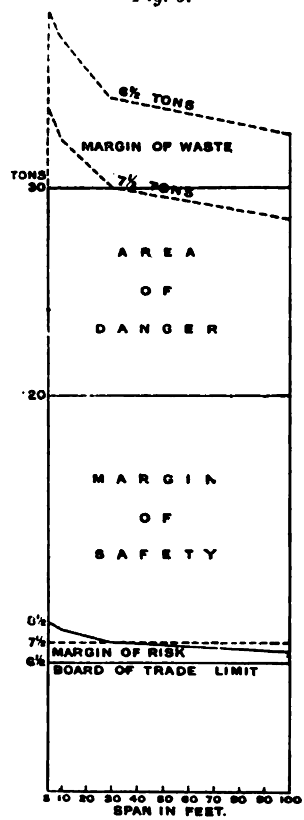
[1] Professor Waddell had suggested a sevenfold classification of moving loads for U.S. railways, which had received the approval of over a hundred chief engineers in America.

Mr. Gribble. iron; but it seemed to him that it was hardly rational to combine corrosion with impact. If corrosion was to be provided for, it should be done not by lumping the live-load assumptions, but by treating each case according to its merits. With regard to the second Paper, the Author had given a very good formula for the longitudinal girders of bridges, which, he thought, would be valuable, if the continuity of the girders were only regarded as auxiliary; but he hardly thought the Author was safe, in his treatment of weak cross girders, in placing a calculable permanent value upon the distribution of the longitudinals, because in so doing he assumed that the continuity of those longitudinals was constant, whereas it was known that the deformations due to wear and tear might very quickly affect the reactions of the cross girders. He thought that when cross girders were weak they ought to be either reinforced or replaced. Speaking without having seen the actual Indian bridge, and, assuming that the flange of the cross girder was as shown in *Fig. 1* of the Paper, viz., only a pair of angles, he thought it would have been an easy thing, even in India, to take the cross girders out one by one and rivet on plates top and bottom. He had placed on the table some models showing work on a bridge in Norfolk that had been repaired by Mr. William Marriott, M. Inst. C.E., a few years ago, where exactly the same kind of longitudinal as the Author had used had been put in, but the old cross girders had been taken out. A more exceptional case was another bridge in Norfolk, also renewed by Mr. Marriott, where the cross girders had not been taken out, but had been reinforced from underneath. The bridge-floor had been underpinned from a stage suspended from the upper boom, the bottom plate of the cross girder had been taken off, and then a sort of subsidiary section of cross girder had been introduced underneath from a stage suspended from the top of the girder. In the first case, the deflection under the moving load had been reduced by more than one-half.

Mr. Thomson. Mr. T. FRAME THOMSON only wished to refer to Mr. Farr's Paper, and was inclined to think that engineers were losing sight of the perspective of the whole matter. He had placed a diagram (*Fig. 6*) on the wall, which illustrated what he had in his mind. It was not now uncommon, as it had been perhaps 10 years ago, to specify for steel a breaking stress of 30 tons to the square inch. The Board-of-Trade limit, which was shown on the diagram, had been fixed at 6½ tons to the square inch a good many years ago, before steel had been so fully studied and so largely used by engineers.

The relation which it bore to the ultimate breaking stress of steel had been a sufficiently reasonable one in those days, giving a factor of safety of about 4. Engineers were accustomed to talk of a factor of safety in rather an offhand manner, without having any clear idea whether there was a reasonable ground for using one factor of safety in preference to another. With regard to iron and steel, he thought there were certain reasonable grounds for adopting a factor of safety of 4, because the results of experiments had shown that about a quarter of the breaking stress was the stress at which steel began to develop a sensible permanent set. Beyond that point, going up the scale towards 20 tons, there was a margin which provided very largely for carelessness in workmanship, which was practically the only contingency to be provided for, apart from the question of corrosion, referred to by the previous speaker. Corrosion was not a matter which should be treated in a rough way by varying the allowances for the effects of moving loads; it was a question which ought to be dealt with by itself in each case. Following the diagram up towards the point where the steel was stressed to 20 tons per square inch, a limit was approached which it was dangerous to allow the stresses to attain. When 20 tons was passed an area of danger was certainly reached. But the point he wished to draw particular attention to in the present case was that apparently the Author had given a great deal of consideration to the allowance which had to be made for moving loads as distinguished from dead loads, and the speakers in the discussion had also dwelt upon the same point. The left-hand side of the portion marked "margin of risk" represented the addition of 30 per cent. to the $6\frac{1}{2}$ tons for which the girder was supposed to be designed; that was, if the girder was designed for merely a dead load, the effect of a live load would be to Mr. Thomson

Fig. 6.



Mr. Thomson. stress it up to 8½ tons, and similarly in varying degree from left to right of the diagram down to 10 per cent. for 100-foot spans. But if the distance between the 6½-ton and the 8½-ton lines was compared with that representing the margin of safety, it did not seem to make very serious encroachment upon the latter; and if the comparison between the 7½-ton line, representing one quarter of the breaking stress of steel which there was no difficulty in getting nowadays, was further taken into consideration, it would be seen that that 7½ tons covered, in the case of the large majority of the spans, the extra stress which could be brought on bridges if they were originally designed for a dead load of 6½ tons per square inch. That was, it covered the increase of stress which the live load could bring on them according to the Author's calculations, and with which many of the members were more or less inclined to agree. At the top of the diagram were two other lines: that part of the diagram had no definite relation to the scale of tons, it was only a comparative portion. The upper of these two lines represented the quantity of metal required in a bridge if it was designed according to the present Board-of-Trade limit, taking into consideration the effect of the moving load: the lower line represented the quantity of metal required if the bridge was designed for a 7½-ton limit, again taking into consideration the effect of the moving load. It would be seen that there was a considerable space between the 6½-ton line and the 7½-ton line. That represented the amount of metal which was wasted, if he was right in his contention that engineers should be allowed to use 7½ tons as a reasonable working-stress for steel under existing modern conditions. Looking again at the "margin of risk" line, it appeared to him that, as the Board-of-Trade limit at present was 6½ tons per square inch, and as the allowance for impact calculated by the Author did not go materially above 7½ tons, any engineer who had the financial interest of his clients at heart was quite justified in designing his bridges without taking the effect of impact into consideration, merely taking the dead loads, unless the Board of Trade was prepared to advance with the times and allow 7½ tons. Its rules only provided for the actual dead load, so far as they had been put into force. He thought he was right in saying that such an allowance was not without precedent; and that in the case of the Forth Bridge, where the steel was guaranteed to be tested to a breaking stress of 30 tons, 7½ tons was taken as the working-stress. If that was so some years ago, it was even more justifiable now, considering the advances which were always

being made and the greater certainty there was of getting specifications carried out. It appeared to many engineers when they heard that the dead load on a particular bridge had to be increased by 30 per cent., that this necessarily implied an increase of 30 per cent. on the material, but it merely meant that a certain margin of safety was being encroached on, which, at present, was greater than it need be by very nearly the amount which the allowances would provide for. Mr. Thomson.

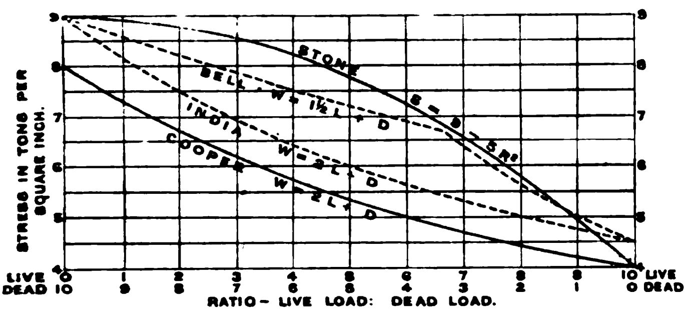
Mr. F. E. ROBERTSON remarked that Mr. Farr's Paper contained some useful information, the result of a good deal of study, and also presented a very fruitful subject for discussion, one which seemed, however, to have been comparatively neglected in this country. With regard to the rules of the Board of Trade, he supposed nobody now took its tests or its rules seriously as things to design bridges by. Some members had suggested that they should be improved, but he was not sure that improvement or augmentation of those rules would be an unmixed joy. He had had to do with discussions on Government rules for bridges and other matters, and his impression was that it was better to let sleeping dogs lie, especially when they were not in one's path. The Board-of-Trade rules covered all ordinary cases, and in extraordinary cases, when desirable, they seemed to be amenable to reason, as in the case of the Forth Bridge, which had just been cited. Regarding the use of the equivalent uniform load, it was of course understood that it would necessarily give, in small girders, a stress much above the truth. He had had occasion lately to compare the results of actual wheel-loads with the so-called equivalent load in certain Tables, and he found the percentage of excess varied from 18 per cent. on the small spans to 14 per cent. at 10 feet, and about 4 per cent. at 100 feet; the excess of course not being uniform, but varying arbitrarily as the different wheels came on. If the live load was doubled, as many bridge-rules required, and a percentage was also added, it was a matter for consideration whether waste was not entailed. Instead of doubling the live load, it would in effect be taking 236 per cent. in some cases. He did not quite like the way in which the Author had divided the effects due to live load into the extra stresses due to impact, caused by the load being suddenly applied; the extra stresses due to the bad state of the permanent way; and the effects of the inefficient balancing of locomotives. He had always understood by impact the effect of shocks, which was the most serious part of the live load on bridges, not the effect of mere quickness of application of the load, which was, he thought, Mr. Robertson.

Mr. Robertson. a different matter. It had been treated theoretically by Professor Melan, who concluded that, owing to quickness of application of the load, there was an increase in the stress varying between 16 per cent. on short spans and 2 per cent. on 100-foot spans. That question of quickness, however, seemed to be one for experiment. It would be possible, in a testing-machine, to ascertain the increase in stress, if any, caused by increased quickness in the application of the load; but, in any case, he did not think it was of much importance in the question of railway bridges, because it was the accidental disturbances which chiefly caused the prejudicial effect of the live load. With regard to very short spans or members, he felt it was a question of mass; it was the resilience of the member that was in question and not its capacity for resisting mere static stresses. One of the most careful attempts to investigate the special effects of the live load had been recorded in a Paper[1] by Mr. Stone, M. Inst. C.E., lately read and discussed before the American Society of Civil Engineers. For the purpose of analysis, Mr. Stone had divided the live-load effect into two, the immediate effect, that was, impact, and the cumulative effect, viz., the constant repetition of the loads; and he had professed to give some facts regarding impact. He had taken some hundreds of observations, made on girders by the Government Inspectors in India at the time of the opening of new bridges, of the standing deflection and the deflection taken at speed; the observations embracing girders of all sizes, up to about 250 feet span. He had plotted those differences in deflection, and through the points thus obtained he had drawn an arbitrary curve to show the average effect of the live load over the dead load.: from that he had derived a curve of allowance for impact. The cumulative effect he had derived from the classical experiments of Wöhler and others who had worked in that direction. The live load thus enhanced, added to the dead load, made the effective working-load for different ratios of live load to dead load. In the diagram (*Fig. 7*) Mr. Robertson had plotted Mr. Stone's proposed rule. Mr. Stone gave a curve in his so-called "range" formula which was the nearest approach to the purely arbitrary curve derived from experiment. The equation was $S = 9 - 5\,r^2$, S being the safe working-stress in tons, and r representing the ratio of the range of stress from the live load to the total load. He also gave, for a case where it was desired to use a uniform working-stress but to vary the load, what he called his "range-

[1] Transactions of the American Society of Civil Engineers, vol. xli. p. 467.

coefficient." The range-coefficient was very easily remembered. Mr. Robertson.
To the decimal fraction representing the ratio of range of stress to total stress unity was added. That gave the coefficient by which to multiply the live load. If, for example, the live and dead loads were equal, say 5 tons live and 5 tons dead, *r*, the range, was 5, and this divided by the total load 10 was 0·5, and 1 added to that made 1·5, which gave the coefficient by which to multiply the live load to give, with the dead load, the total effective working-load. The Government of India rule was a fairly simple one. It was represented by the lower of the two dotted curves in the diagram. A uniform stress of 9 tons was taken for steel, and the working-load was taken as twice the live load plus the dead load; for the chords of truss-bridges, however, a coefficient of one and a half times the live load was used. The rules of Mr. Stone and the Government

Fig. 7.



of India, and other cognate rules, were based on the assumption that as much as 9 tons could be used for the dead load, and experience showed that it was not possible to go beyond 4 tons or 4½ tons for very short spans, which was represented at the lower ends of the curves. Stone's rule, it would be observed, was very liberal as the dead load increased. The Government rule, with a coefficient of 2, was a long way below it. It might be mentioned that the Government rule up to the region of 7½ tons was identical with Morison's rule. Mr. Robertson had also drawn on the diagram the curve for a rule evolved by Mr. J. R. Bell and himself while the discussion was going on about the Government of India rules. That rule was frankly empirical, as would be seen by the cusp in it, a thing which no rule with scientific pretensions could possibly admit. The formula for it was very simple, however. It was that the effective working-load was 1½ times

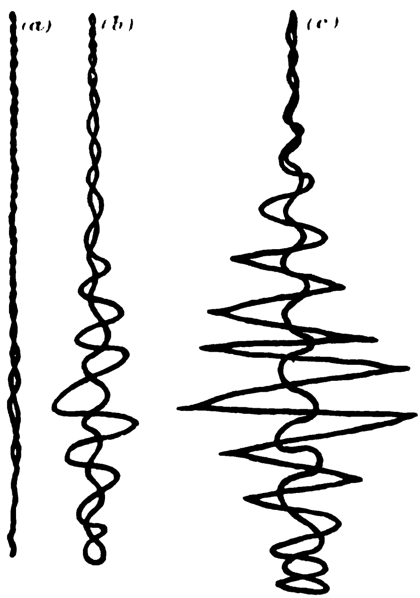
Mr. Robertson. the live load plus the dead load, with the restriction that the dead load must never be taken at less than half the live load. It was, in fact, an attempt to draw together the two distinct Government rules, the one for web members and the other for chords. Possibly it would be better to use the coefficient 2·1 for the dead load in the smaller spans; for practical purposes it had the merit that in short spans it was not necessary to trouble about the dead load at all, but simply to take the live load and multiply it by 2 or by 2·1. The top segment of the curve was, of course, as far as it went, identical with that representing the Government rule for chords, viz., $1\frac{1}{2}$ times the live load. Cooper's rule had also been plotted as a well-known, largely used, American example. Its formula was identical with the Government of India rule, $W = 2 L + D$, but the constant was rather smaller than was used in the latter. Rules such as those of the German Government and others, which depended upon an arbitrary unit stress for different sizes of span, could not well be shown in the diagram; and it must be remembered that it was impossible to show the whole truth in a diagram, since the administration of different rules might vary more than did the rules themselves. Comparing, for instance, the Government of India rule and Cooper's, in applying the former a type of engine was used which exaggerated the effect it was possible to obtain with the wheel-loads permitted under Government rules. Then these engines were supposed to be coupled head to head in the middle of the train, or in any other position that might give the greatest stress in the case under consideration. Further, every ounce of wind-pressure or centrifugal stress had to be accounted for in the sections, and net sections only were taken for compression members. On the other hand, Cooper's rules only required the engines to be in their usual place at the head of the train, and the sections of members were not increased until the wind-pressure and other subsidiary stresses amounted to 25 per cent. of those due to the loads: hence it might well be that, although the Government rule appeared to be the more liberal one, yet when fully worked out it might require more metal than that of Cooper. The only way to represent the real effect of different rules in a diagram would be to work out actual examples for the several ratios of live and dead load. His own convictions in the matter were purely negative. He declined to accept any formula as more "scientific" than another, because in the present state of knowledge he believed them all to be equally empirical. The principal point was to secure a rule convenient to work with, and keeping within the

limits sanctioned by experience; and it seemed to him that this was best attained by using a fixed unit stress and applying a coefficient to the live load. To vary the permissible stress made it difficult to use tables of rivets, etc. The Author concluded by proposing to adopt a less allowance for live load than was made by Professor Melan; but Mr. Robertson would point out that the Professor, in summing up, stated explicitly that the allowances which he had deduced theoretically were probably too low on account of accidental conditions. As the Author did not give the unit stress with which he proposed to combine his effective working-load, it was impossible to judge of the effect of his proposal. Should that stress be the 6½ tons of the Board of Trade, Mr. Robertson made out that the Author's static stress for a short span would be 4·9 tons, which in his opinion was much too high, and the maximum would be 6½ tons, which was certainly too little for long spans. On Mr. Findlay's Paper he need only remark that it was welcome as a general and easy solution of a case which not infrequently arose in connection with old bridges, and with new ones in the case of trough-floors. Where the Author's formula did not apply, as in the case where the cross girders differed in rigidity, the solution of a particular case was very tedious. He had had such a case in dealing with these old bridges, where every third cross girder was very strong and was built right through the top chord and post, while between these strong girders were two very weak ones. Mr. Gribble had objected that he would rather have expended the money in strengthening the cross girders, but Mr. Robertson thought he had not quite appreciated the fact that there were originally no stringers at all, and since they had to be provided, it was well to make them strong enough to reduce the load on the cross girders. Mr. Robertson.

Sir GUILFORD MOLESWORTH, K.C.I.E., had had some considerable experience in testing bridges under trains at high and low speeds, and his experience went far to confirm Professor Unwin's opinion, that the curve of deflection was not influenced whatever the speed might be. Some fifty years ago he had taken the deflection of a 60-foot plate-girder bridge on the London & North Western Railway, by a deflectometer invented by Mr. Harry Warriner, which reproduced the deflection about five times its actual size; and he had been surprised to find that the deflection at a high speed was not greater than that at a lower speed; in fact, it was slightly less than that which was due to the test train standing on the girder for some minutes. Since that time he had had occasion to examine some hundreds of test-diagrams taken Sir G. Molesworth.

Sir G. Molesworth. with an arrangement by which a pencil recorded not only the deflection but the vibration of the girders, and he had found, as a general rule, that at high speeds the deflection was not materially, if at all, greater than at low speeds. He must, however, admit that these tests had been made on girders of long span 100 feet and upwards, in which the mass was very great compared with the impact of the passing train. Also, the girders had been new, and consequently the permanent way was in first-rate order, the engines were well balanced, and the speed was nothing like the high speed

Figs. 8.



of express trains on English railways. *Figs. 8*, (*a*) (*b*) (*c*) showed what he considered to be very fair types of test-diagrams, the vertical movement representing the deflection and the lateral movement the vibration. (*a*) represented the diagram with an engine crawling upon the bridge; (*b*) represented that taken with an engine passing over at a moderate speed, and (*c*) that at a high speed. He had found as a general, though not universal, rule that the maximum vibration occurred at about three-fourths of the maximum deflection. That would apparently represent a condition when the leading locomotive was nearly at the centre of the bridge; and

that again, he thought, confirmed Professor Unwin's statement, that the unbalanced working-parts of a locomotive were the greatest factor in producing vibration. He must explain that in those tests, although the train consisted of two engines and a large number of loaded wagons, the leading locomotive alone was in steam, and therefore it was the disturbing factor in the test-diagram. Reference had been made to the fact that whilst in bridges requiring renewal the cross girders were found to have failed, the main girders remained comparatively sound. In the absence of any information as to the design of the girders, their mode of attachment, the manner of bracing, and the character of the failure, it was impossible to give an opinion as to the cause of that failure. There was, however, he thought, one factor which was generally overlooked, namely, that under certain conditions the cross girders might be exposed to a very severe lateral stress, which they were neither intended nor calculated to resist. He alluded to the stress caused by applying the brake suddenly when on a bridge, the drag on the rails being communicated to the cross girders. He thought it very possible that stress of that sort might come on some of the cross girders to such an extent as to exceed the limit of elasticity, thus crippling them so that they failed under ordinary traffic. The plan generally adopted on the State Railways in India of decking or flooring the bridges would, of course, minimise that stress by transmitting it to the main girders and to the flooring generally. The prevalence of the continuous brake of late years had added to the intensity of such stresses. Mention had been made of the fact that in America the girders were designed for axle-loads of 11 tons for light railways, and 19 tons for heavy railways. He had had a good deal to do with light railways (the metre-gauge railways in India being the light railways, and those of 5-foot 6-inch gauge being the heavy railways), and he must confess that he was sceptical about light railways, especially with regard to the plan of designing light girders for light railways. It was, he thought, almost impossible to keep the loads within the specified limits. Stipulations might be laid down and they might be fenced with regulations, but the fence would be broken down sooner or later. New men came to the front; those who had framed the regulations passed away; the traffic increased beyond anticipation, the railway officials pressed for larger wagons and the locomotive engineer for heavier engines; and by degrees the light railway became a heavy railway, and the girders were found

Sir G. Molesworth.

Sir G. Molesworth. to be too weak. There appeared to be a general tendency to over-rate the economy to be gained by light girders. It must be remembered that the total cost of a railway was made up of a great many items besides girders, the cost of the latter being only a small fraction of the total cost; whilst the difference in cost between light and heavy girders was still smaller. Among the other items were:—preliminary expenses, surveys, land, earthworks, rock-cutting, tunnels, retaining walls, culverts, abutments, piers, river-training works, level crossings, telegraphs, ballasting, permanent way, stations, staff-quarters, workshops, plant, machinery, establishment, &c. With a view to ascertain the relative saving to be effected on railways, he had instituted an analysis of the estimates of forty-two light railways and of twenty-eight heavy railways with which he had been officially connected; and he had arrived at the conclusion that in those seventy railways the economy to be gained by the difference in cost between light and heavy girders amounted to something less than 3 per cent. of the total cost.

Dr. Brightmore. Dr. A. W. Brightmore said that one of the most interesting points raised in the discussion was the assigning of the proper working-stress to the various members of a bridge. With regard to that there seemed to be some difference of opinion on the part of the authorities. The crux of the whole question appeared to be, whether Wöhler's results were to be taken to imply reduction in the strength of the member, or simply to indicate the effect of the dynamic action of the load being suddenly applied. If it were assumed that they indicated a reduction in the strength of the member, and if also an allowance were made for the dynamic increase in the stress, factors of safety would be arrived at which practice had shown to be unnecessary; but, on the other hand, Wöhler's results were what would naturally be anticipated in the case of loads being suddenly applied to a more or less elastic body —for the dynamic increase in the stress coincided with the reduction of strength indicated by Wöhler's results—and if it were assumed that Wöhler's experiments were simply a confirmation of theory in that respect, it was only necessary to add to the static stress the dynamic increment due to the load being suddenly applied. As had been already pointed out, the dynamic increment of the stress was equal to the range of stress in the particular member under consideration; consequently, when the load was suddenly applied, it appeared to be only necessary to add the range of stresses in any member to the maximum static stress in that

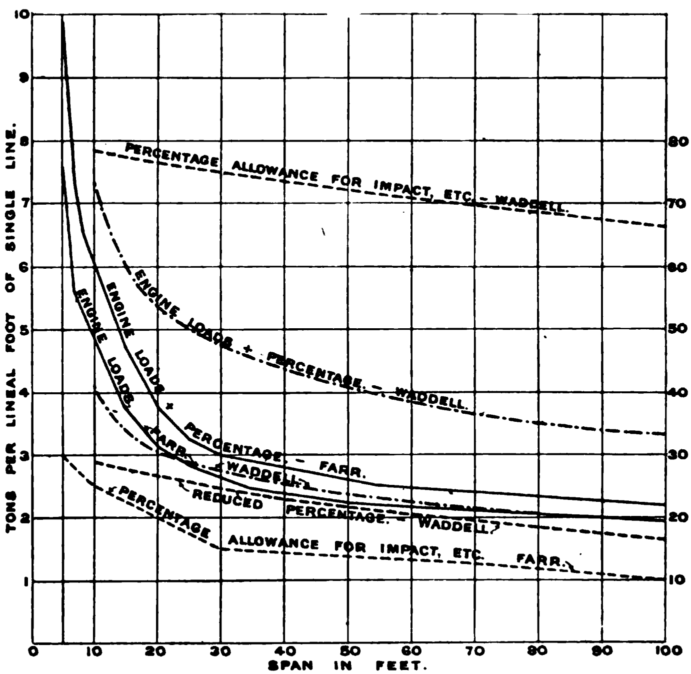
member, to and use a constant factor of safety for all the members of the bridge. In a short girder, in cross girders, and in the case of bracing, the load of the train came on very suddenly, and in that case no doubt the whole of the dynamic increase of the stress should be added; but in the case of long girders the load was not very suddenly imposed on the flanges, and consequently it would probably be necessary to add only a portion of the possible dynamic increase of stress. In that manner, by using what might be called the coefficient of "suddenness of application of the load," allowance could be made for the load coming on suddenly or more gradually. The formula of Launhardt and Weyrauch, which had been referred to, did not allow for that variation in suddenness. Therefore it appeared to him that the dynamic method, besides being simpler, also gave more scope for allowing for the degree of suddenness of application of the load than the formula referred to. Dr. Brightmore.

Mr. G. E. CRUTTWELL said the suggestion of the Author of the first Paper that the rolling loads of bridges should be standardized, had been already carried out to some extent in America, and he thought a few particulars comparing the American system with that suggested by the Author might be of some interest. The American standard system of rolling loads on railway bridges, initiated by Mr. J. A. L. Waddell, M. Inst. C.E., in 1891, had been described by him in a book[1] published in 1898. Mr. Waddell dealt with seven classes of rolling loads of varying weights, beginning with Class T, in which the engine and tender weighed 129 English tons (the axle loads being 19 tons) on a length of 52 feet, and ending with Class Z, in which the engine and tender weighed 83½ tons on a similar length. Mr. Waddell had reduced the loads from those various engines and tenders to equivalent uniform rolling loads. The American diagrams were given in pounds, but Mr. Cruttwell had converted them to English tons, and he found that Mr. Waddell's diagrams of equivalent uniform loads for Class W, which was his mean class, the engine and tender weighing 106 tons on a length of 52 feet, corresponded very nearly with the diagram which the Author gave for maximum engine-loads. In *Fig. 9* Mr. Waddell's line was shown by a dotted line and the Author's line of maximum engine-loads by a full line. In the same Figure all the other lines given in Mr. Cruttwell.

[1] "De Pontibus." New York and London, 1898.

Mr. Cruttwell. the Author's diagram (*Fig. 1*) were shown. Mr. Waddell's line was identical with Mr. Farr's line for spans between 100 feet and 80 feet, and coincided again at the span of about 24 feet. On the whole the two lines agreed very closely. But with regard to the percentage allowance he found the figures varied very much. The top line he had worked out from a formula which Mr. Waddell gave for percentage to be added for impact, &c., which was equal to 40,000 divided by the span in feet + 500. Mr. Waddell anticipated that engineers would consider

Fig. 9.



that percentage very high, but, as he said, it included allowance for incorrectness in shop-work, or as he called it, the factor of ignorance. Mr. Waddell did not say how much he allowed for ignorance and how much for impact, but Mr. Cruttwell thought it might roughly be obtained, because it was fair to assume that the percentage for ignorance would be the same whatever the span, and also it could be assumed that the impact would die away to nothing at a span of about 300 feet. Working on these assumptions, for a span of 300 feet it would

be found that the allowance for impact and ignorance came to 50 per cent.; but as impact was zero at that span, the allowance for ignorance must be 50 per cent. Deducting that 50 per cent. from the upper line the lower line was obtained, which was on the average about 10 per cent. more than Mr. Farr's percentage. He hoped the ignorance was not quite so much as 50 per cent. in this country, and he thought something very much less than Mr. Waddell's practice might be adopted. At the same time he did not think anything less than Mr. Farr's ought to be adopted. The President's remark that his own practice was to allow more than Mr. Farr gave, bore out the view he was putting before the meeting. There was one other matter which he thought had not been alluded to in the discussion, and that was the extra force exerted on the lee rail due to the action of the wind on a passing train. He did not want to assume anything like the Board of Trade's 56 lbs. per square foot, as he believed an ordinary carriage would be blown over at something between 30 lbs. and 35 lbs. per square foot, and that did not often happen. If 28 lbs. per square foot was reckoned on an engine and tender passing over a 50-foot bridge, he thought it would be found that there was on the lee rail a downward force of about 12 tons throughout the length of the bridge. From the Author's Table the maximum load for a span of 50 feet was 2·24 tons per lineal foot of single line, which worked out to about 112 tons on the whole 50-foot bridge, or 56 tons on each rail. If to that were added 12 tons additional downward force on the lee rail, caused by the wind on the passing engine and tender, there was obtained $56 + 12 = 68$ tons on the lee rail and only $56 - 12 = 44$ tons, on the weather rail. In the case of an ordinary bridge, with girders 14 feet apart, that meant an extra load on the lee main girder of about 4 per cent., giving 54 per cent. on the lee girder and only 46 per cent. on the weather girder. If the main girders were closer together, as in the case of rail-bearers, that increase in the load might amount to as much as 10 per cent., giving 60 per cent. on the lee bearer and only 40 per cent. on the weather one. He did not think that had been considered in the Author's percentage, and he thought some allowance ought to be made for that fact. Mr. Cruttwell.

Mr. F. Hudleston said there was one remark in Mr. Farr's Paper which had not been dealt with by previous speakers. The Author remarked that owing to the limitations of loading-gauge he considered the rolling load of steam-locomotives was not likely Mr. Hudleston.

Mr. Hudleston. to be greatly increased. No evidence was adduced in support of that proposition. He knew of one case, a pair of heavy tank engines built for yard-work on the Central London Railway, in which, although the engines were well-balanced, the load per lineal foot of wheel-base was about 3½ tons, a higher load than any mentioned by Mr. Farr. Those engines were for very special work, and carefully built for giving the greatest possible power. The ordinary standard railway in England had a loading-gauge 50 per cent. larger in area than that of the Central London Railway, and if an engine-builder in England could manage to build well-balanced engines with a load of 3½ tons per lineal foot of wheel-base, he thought any locomotive superintendent could get heavier loads on a standard road when they were necessary. Tank-engines, and engines of moderate size, were often a great deal heavier for their wheel-base than bigger engines, but if such a weight could be crowded into a small loading-gauge, only two-thirds of the standard, it showed there was a possibility of increasing the weight of steam-locomotives considerably above existing practice. With regard to Mr. Findlay's Paper, it bore a great deal on continuous floors, which were becoming so common in England. No one had yet invented a continuous floor which would actually distribute the load of a pair of wheels to any considerable extent. He thought that, as rolling loads increased, rail-bearers would have to be adopted to a greater extent than they had hitherto in continuous floors. The Author's equation unfortunately applied only to a single line. He suggested that some member who was a good mathematician should work it out for a double line of rails.

Mr. Bell. Mr. J. R. BELL remarked that Mr. Farr's Paper was an essay upon a subject of universal interest, illustrated by a number of important examples. It was difficult, in debating a question of that kind, to avoid ground already covered by experts of eminence in the subject under discussion. The labour involved in the preparation of the diagrams in Mr. Farr's Paper had already been dwelt on by Prof. Unwin, whom Mr. Bell, in common with a great many men both young and middle-aged, almost looked upon as their Nestor in matters connected with girders; and the beauty of Mr. Findlay's antidote for the axle-load bane had been freely and gracefully acknowledged. He had scrutinised with some interest the results obtained, and he thought it would be of value if Mr. Farr would explain some points which he ventured to think were obscure. Some allusion had been made to an apparent mistake in the Table of Great Western axle-weights, seeing that there

actually was a class of engine with 19 tons on a driving-axle running on that line. Mr. Bell had noticed another point. In the diagram relating to the Great Western Railway, at the ordinate which represented a span of 10 feet, it would be found that the single dotted line referring to a goods engine indicated that something like 4·8 tons or 4·9 tons per lineal foot was not the result of adding the allowance of 30 per cent. for impact and repetition of stress, but the net static load due to that particular engine; 4·8 tons per lineal foot on a span of 10 feet was equal to 48 tons distributed, which was equal to 24 tons at the centre of the girder. Twenty-four tons at the centre of a 10-foot span was unattainable with any known axle-load, because it was practically impossible to get two axles in a standard-gauge engine closer together than 5 feet, or at any rate 4 feet 6 inches; so that with one axle over the centre of a 10-foot span, giving the maximum bending moment due to its load, the moment of the next axle-load at the centre would be at most a tenth of the moment of the other. He might perhaps be labouring a trivial point, but it was particularly noticeable, in the diagram which Mr. Cruttwell had referred to, that Mr. Farr's engine-load, according to the full line for a 10-foot span, went up close to 5 tons, where Mr. Waddell, who, like most American bridge-engineers, certainly did not err on the side of under-estimating the possibility of locomotive engineers' assaults on his work, only gave 4 tons. With regard to Mr. Farr's view, which another speaker had touched upon, namely, that the limit of the capacity of the gauge for bridge-loads as affected by engines had been reached, those acquainted with American practice, if only on paper, would recognise this as far from the probable facts of the case. Mr. Morison, an expert of the first distinction in America, was one of those who adopted a kind of type locomotive, and he had found that the effects of the heaviest engines now in use could be practically represented by drawing an engine with four axles spaced at 5-foot intervals, loaded with 50,000 lbs. per axle; in other words, something like 22·2 English tons per axle, on four axles, say 90 tons or thereabouts on 15 feet. His type tender had exactly half that weight, viz., 25,000 lbs. on each of four axles 5 feet apart, and there was a clear interval of 15 feet between the wheel-base of the engine and that of the tender. Not only so, but one of the speakers on a Paper read lately in America went so far as to say that he saw no practical limit to the weights that might be put on engine-axles in America, unless it were the limit of the weight that would crush the head of the rail. It

Mr. Bell.

Mr. Bell. evoked a smile at the present time, but it might come within the scope of good practice in the next quarter of a century, to discuss whether it would not pay railways to use nickel-steel rails, so that the heads should not crush under the enormous loads which he anticipated would be put on the same gauge. In America they had long ago increased the loading-gauge, and he supposed the time was approaching when it should be altered in this country. The 6-foot way between lines was already an anachronism and a nuisance, and threatened, as between goods lines and fast traffic lines, to be a serious public danger. There had been a good deal of discussion in India, since Sir Guilford Molesworth's time, upon the question of the life of girders, and, as in Mr. Inglis's experience at home, it had been found that old main girders designed 30 years, or even 40 years ago, were perfectly sound and good, exhibiting no signs of deformation in booms and main members, which had no doubt been designed under the Board-of-Trade rule of 5 tons per square inch. On the other hand, anxieties about floor-members and small spans were numerous, and indeed serious. Undoubtedly the original axle-loads had been increased, and the speeds also, but the roads were exceedingly well kept. He thought the 5-foot 6-inch gauge conduced on the whole to keeping the roads in good condition, for it was easier to maintain a good road with a 5-foot 6-inch gauge than with a 4-foot 8½-inch gauge, given the same weights on the same rails. Each rail could be kept up to within, say, an inch above or below a true plane, and the wider apart the rails were spaced the less angular motion or lateral sway would be induced by a given irregularity in packing the rail. In India, as in England, it was found that the cross girders and longitudinals of large bridges were the chief or rather the only sufferers. That had brought a distinguished engineer, for many years Sir Guilford Molesworth's personal assistant, to consider the matter, and he, curiously enough, had come back to the conclusion originally formulated by the Royal Commission in 1849, and quoted in Mr. Farr's Paper. That conclusion, with which Prof. Unwin seemed now to agree, was that the effect of live load, at any rate upon small spans and parts immediately attacked, so to speak, by the engine, was exactly double that of an equal dead weight. The formula as introduced in 1849 and quoted in the Paper enacted that the breaking stress of a cast-iron girder must not be less than three times the permanent load due to the superstructure added to six times the greatest moving load. It would be seen that a general factor of safety of three was applied to the quality of metal, and a further factor of two for live load, thus

estimated at twice its weight. It was on that basis that the rule affecting short spans and the parts, other than booms, of long spans had been drawn up in India, as shown in Mr. Robertson's diagram, where W (the working load) equalled 2L (twice the live load) plus D (the dead load). Though most proper for members attacked directly by axle-loads, 2 was far too high a coefficient for live loads and the booms of large main girders. There was the patent fact, which he thought would be found in Prof. Unwin's book on the subject, that the Britannia Bridge was stressed to something like 7 tons per square inch—certainly a long way beyond 5 tons per square inch, merely taking the actual axle-loads without any increase for impact, and adding them to the dead load of the bridge. In Sir Guilford Molesworth's pocket-book it was stated at 5·95, but that perhaps was calculated when engine-loads were nothing like so heavy as at present. If the Author was right, scraping of the Britannia tube must, in the course of 49 years, have appreciably reduced the metal. Tons of scrapings were said to be taken out every year, and though a good deal of this was doubtless oxygen and paint, some must be iron. Moreover the live-loads had been added to, but the bridge was still in use without giving any recorded anxiety. That and many minor examples seemed to prove that if 2 were the right factor for all live load, 1 should suffice where the proportion of live load to dead load was as small as, say, ½. India had empirically adopted, in conjunction with 2L for other members, 1½L for booms of trusses, and as long as the latter coefficient was not applied to spans less than 100 feet the rule gave good though occasionally illogical results. To say that the same coefficient might be used for live load, whether there was a considerable dead load or not, seemed like saying it would equally affect the product, whether the iron was hammered on the anvil or the anvil on the iron. He did not use that as an argument, but in illustration of what he meant, namely, that the shock-absorbing effect of a massive load must be very considerable. The effects of rolling loads, however, on those members which sustained considerable dead-load stresses did not in fact produce shocks, but arose and subsided piecemeal, culminating but once for the passage of a train. Wöhler had investigated the effect of intermittent loads of this class on test-bars, and found that it did not matter what dead load was added until almost the utmost permanently-supportable dead load was reached; and that the bar could bear slow accessions of live load, until the temporary maximum was more than the Mr. Bell.

Mr. Bell. bar could bear as a permanency. It had been remarked that the objection had been raised that the stresses in Wöhler's experiments exceeded the elastic limit of the material. No doubt in the sense in which Mr. Max am Ende had intended, Wöhler's stresses did exceed the normal or original limit of elasticity of the material, but surely the immediate limit of elasticity was the limit that could be borne at the time, and Wöhler, or at least Bauschinger, showed that repetition tests raised that limit for at least the time being. He had arrived at the conclusion that for spans where the dead load was equal to, or even somewhat greater than, the live load, it was quite possible to design girders in a satisfactory and accurate manner, by ignoring the dead load altogether, and figuring solely upon the live loads which came into the question. Up to a certain limit the dead load would entirely take care of itself, if the weight of a properly proportioned girder were treated as negligible, and a square inch of section (plus due allowance for column formula, etc.) were allowed to, say, each 3 tons of live-load stress in iron, and perhaps each 4 tons in steel. Thus a cross girder having no dead load to speak of, would be stressed its 3 tons or 4 tons per square inch, while a main girder with considerable dead load would get its 5 tons or 6½ tons, and, but for Board-of-Trade rules, even more. These live stresses would intersect the Board-of-Trade rule at 2 dead to 3 live in iron, and 2½ dead to 4 live in steel. He would add half the wind stresses to the main stresses. This thesis might or might not interest English designers, but he understood that most designers had fixed ideas as to what the actual weight of a girder would prove to be, and were not in the difficulty which Mr. Ross had mentioned, namely, that after the girder had been designed, its weight had to be calculated, and then the girder had to be designed again, combining its own weight with that imposed upon it. Mr. Bell had found this uniform live-stress method at least as accurate as the Weyrauch and Launhardt formulas used in America, and hoped some day to show that, although an accidental discovery, it had a not wholly unscientific basis.

Mr. Thorpe. Mr. W. H. Thorpe said that one thing about Mr. Farr's Table which particularly struck him was the limited difference between the stresses nominally developed in a girder of 5 feet span, and those in the longer span of 100 feet. If, working to that Table, and making reasonable and proper allowances for dead load, the sections were deduced, and then the stresses were estimated with reference to static effects alone, it appeared that with a 5-foot

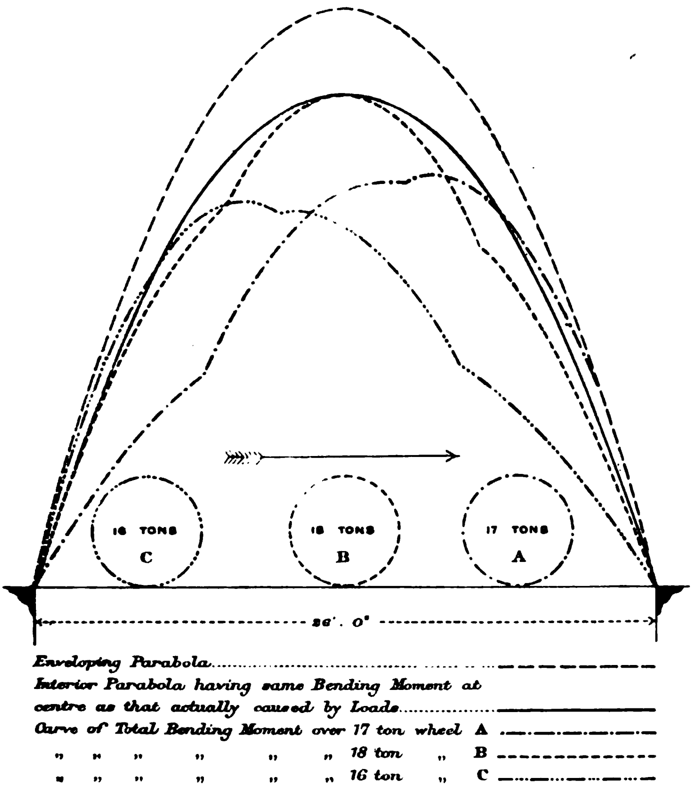
span there would be about 3·91 tons per square inch, and with a Mr. Thorpe. 100-foot span 4·73 tons per square inch, for wrought iron. That gave a difference of stress of 0·82 ton between the short and the long spans. If the same was done with the French rule for wrought iron, a difference of 0·62 ton resulted. The Indian rule, as he understood it, gave a difference of 2·2 tons for steel, and applying Prof. Melan's results he found a difference of 2·5 tons. So far as his own observation and experience went, he hardly thought Mr. Farr's rules made a sufficiently large allowance, in regard to the effects of one sort and another which had been named, for the difference that undoubtedly existed between extremely short and longer spans. It was evident to any one who had stood under the floors of bridges and watched their behaviour with engines running over, that the suddenness of application of the load made a very material difference. An engine running at 50 miles an hour would travel from the abutment to the centre of a 5-foot span in $\frac{1}{30}$th of a second; to the centre of a 100-foot span it would take twenty times as long. He would not attempt to say exactly what difference that made, but it was manifest it must make some. In very short girders the amount of drop would not be measured by the deflection alone. Small girders sat lightly on their abutments; the bed-stone might be a little bit shaky, and the amount of drop of the engine-wheel, by the time it reached the centre of the small span, might thus be twice or three times as great as that due to deflection alone. But apart from the reasons, the facts were that small girders and bridge-floors failed, even when moderately stressed, and that, as had been already said by several speakers, main girders might be stressed highly with reference to the Board-of-Trade rules (even 50 per cent. higher than those rules would allow) without showing any signs of injury. He had never seen any large girder fail, or show any signs of failure, on account of high flange-stress, though he had known the stresses run up to 7 tons or 8 tons per square inch for wrought iron. Small girders, however, would occasionally fail at stresses well below 5 tons, not by failure of the flanges, which he had never known to happen, but by working of the rivets, loosening of the end connections, and perhaps vertical cracking of the webs. With reference to cracking of the webs, he thought it might be as well to say that that by no means indicated particularly high stress or ill-usage of the metal. There was a time, he believed, in the history of metallic bridge-construction, when engineers, with the idea that, for practical reasons, the web of a girder could not be reduced towards the middle so much as they wished, made a virtue

Mr. Thorpe. of using inferior iron for the central part. He had seen many girder-webs cracked, and the only way in which he could account for fractures in a vertical direction was that inferior iron had in fact been used, and that under the stress to which the girder was subjected the metal was unable to maintain its integrity. He was certainly an advocate of low stresses in bridge-floors, not wholly because of the effects which had been elaborately investigated, more particularly by German scientists, but as the result of practical observation. It was evident that the lower the stress the less the deflection, and the soundness of small girder-ends where they were attached to larger girders was very much affected by the amount of deflection of the smaller girders. He thought if the inclination that the end assumed when the girder was under stress was limited, there would be a better chance of keeping the joint intact; and, further, he thought better means of attachment might be devised. There was commonly a very abrupt break in the section of the cross girder at that part of the main girder to which it was attached. It was an axiom in machine design that there should be no sharp hollow corners. In a shaft of one piece of varying diameter, the reduction in diameter was brought about gradually and with rounded corners, not by an abrupt change with square corners; and he thought the same principle might be applied with advantage in designing cross-girder attachments to main girders. In some such way that harsh incidence of stress at the connection, which worked so much mischief, might be done away with.

Mr. Sadler. Mr. H. W. Sadler wished to make a few remarks about the so-called equivalent uniformly distributed loads. He had seen a number of Tables of such loads, and had no doubt that they would be published before long; and he thought it was desirable that the members should first consider on what basis they were calculated. They were so arranged that a parabola should be drawn for the bending moment. The curve of bending moment for a uniformly distributed dead load was a parabola; the curve of bending moment for a single rolling load was a parabola; but the curve of bending moment for a number of rolling loads was not a parabola but a much more complicated figure. *Fig. 10* showed the actual curves of bending moment caused by three rolling loads traversing a span. The diagram was an example of a 26-foot girder with a Great Northern engine giving axle-loads of 17 tons for the leading wheel, 18 tons for the centre wheel, and 16 tons for the trailing wheel. If it were assumed that the engine was moving in the direction of the arrow, wheel A came on and produced a curve

which was a parabola so long as it alone was on the span, but when the wheel B came on the span it threw up the curve, and when wheel C came on the curve was again deflected. The curves over the other wheels were produced in a similar manner. The result was a number of curves with cusps, and the actual bending-moment for the girder curve took that form. If a parabola were drawn which was tangent to the curves at the haunches it would be found Mr. Sadler.

Fig. 10.



to go considerably outside them at the centre, as shown, and that had been called correctly an "enveloping" parabola. If an interior parabola were used, having its maximum moment at the centre equal to that caused by the loads, it would come inside the actual bending-moment curves at the haunches. What he wished to know from those who advocated a system of Tables was, was the enveloping parabola or the interior parabola to be taken?

Mr. Sadler. because there was a difference of something like 20 per cent., which was considerable. He would give a few figures bearing on the question. The enveloping parabola was excessive to the following extent:—For a 25-foot span 19·8 per cent.; for a 50-foot span 19 per cent.; for a 60-foot span 18·6 per cent.; for a 100-foot span 12·5 per cent. The deficiency in the case of the interior parabola was not so great as the excess in the other, and was as follows:—For a 25-foot span 13·6 per cent.; for a 50-foot span 8·8 per cent.; for a 60-foot span 8·7 per cent.; for a 100-foot span 3·7 per cent. That difficulty about the greater depth of the curve at the haunches had been referred to, and it had been said that it was easy to get over that by lengthening the cover-plates at the haunches; but how much they were to be lengthened was not stated, and he supposed it was to be left to the judgment of the draughtsman. It had also been stated that the sectional area of metal actually provided in a girder of short span would be the same throughout its length as at the centre, and therefore the deficiency at the haunches would not occur. That might be the case if the girder was deep, but if it was shallow and more than one plate was required, where were the plates to be stopped short? He did not see what difficulty there was in drawing an actual bending-moment diagram for each span. He would like to consider what was the utility or desirability of preparing general Tables of the kind proposed. They were not applicable to skew spans where the maximum bending moment was sometimes considerably to one side of the centre; and it was the experience of most engineers that more than half the bridges which had to be designed were skew bridges. Further, the Tables could not be used for the shearing-force diagram. If the enveloping parabola were used, as proposed by the Author, the quantity of metal would be increased considerably at the centre, which would not add uniformly to the strength of the girder, as the increase would not be maintained at the haunches. If it was thought necessary, considering the possibility of the increased weight of engines in the future, to provide metal in excess of that at present required, it should be done with a regular percentage throughout the girder. If Tables were published, he thought they ought to be called "approximate" Tables, and not published as though they were actually correct. They were not, and could not be, correct if they were used for parabolas. If the word "approximate" were added, he thought the Tables might be useful for preliminary purposes, but he did not think they could be correctly used for working-drawings.

Mr. C. E. STROMEYER said that, a few years ago he had taken engineering students in Glasgow to the docks swing-bridge, and had experimented on it with a view to ascertain the bending stresses that occurred in its individual bars. He believed that in text-books a lattice girder was always considered to be hinged at the corners, but it was quite evident that in reality the hinges were rigid, and that if there were lengthening of any one of the bars as compared with the others, as there must be when they were stressed, there would be a tendency to change the angles at the corners, leading to local bending of the bars, which would take a sort of S curve. The instruments used showed very clearly that there was a different bending stress at one end of each bar from what there was at the other end, and he believed that was the first time the matter had been demonstrated experimentally. It was thus found that in struts or lattice girders the individual members were subjected not only to axial stresses but also to bending stresses, and that therefore the rigidity of such a girder was greater than assumed and also the local stresses. He did not know whether this was taken into account in the design of bridges, but he could quite conceive that under extreme cases of design it ought to be. With regard to the live load, which had caused so much discussion, he believed that the diagrams which Sir Guilford Molesworth had shown, indicating that the deflection was not so very much greater for a high speed than for a low speed, was quite in accordance with theory, and engineers ought to study that theory of impact more closely. The text-book theory was that the stress produced by a live load was double that which would be produced by a dead load of equal amount, but this depended entirely on the speed of the deflection and the inertia of the beam and load. The mathematical investigation assumed that the full load was placed on the bar, which at once moved down and suffered double the stress; but if the load were slowly put on in an appreciable period of time, like a train passing over a bridge or a jockey-weight on a testing-machine, the stress would not be doubled. Again, if the load were actually dropped on the beam the stress would be very much more than doubled. The whole question required investigation, and would, he thought, explain the difference between long and short girders. Mr. Stromeyer.

Mr. S. HEATON-ELLIS thought it would appear from Mr. Inglis's remarks that in comparison with the cross girders the additional stress caused by the moving load over the dead weight had very little effect on a properly designed main girder. If Mr. Inglis Mr. Heaton-Ellis.

Mr. Heaton-Ellis. could kindly supply some further details of the cross girders, particularly as regards the connections with the main girders, it would materially assist in coming to a conclusion with regard to the Tables given by Mr. Farr.

Mr. Gilbert. Mr. W. Gilbert remarked that nothing was said in Mr. Farr's Paper about the shearing force at various sections of the spans. The shearing force at any section had to be known because the sectional area of the web and the rivet-pitch depended on it. As pointed out by Professor Unwin, the shearing force could not be obtained from the value of the uniformly distributed load given in the Tables, and it was interesting to see what the error was. On a span of 100 feet, loaded with two passenger engines and a train weighing $1\frac{1}{4}$ ton per lineal foot, the shearing force at the abutment worked out to about 6 per cent. greater than the value deduced from the equivalent rolling load, as estimated by Mr. Farr. For a 20-foot span the shear at the abutment was 5 per cent. greater than the value calculated from the uniform rolling load. The excess for this span would be much greater but for the fact that the parabola largely over-estimated the bending moment at the cêntre of the span. Regarding the allowance to be made for impact, Mr. Farr did not give details of the observations on which his own figures were based; possibly the allowance was small for the short spans. The results of the experiments made by the Railway Commissioners in 1849 were shown in column 2 of the annexed Table. The velocities reached 50 miles per hour. The allowance for impact proposed by the Author was shown in column 3. With regard to the working-stress, the formula authorised a few years ago by the French Government seemed very useful. The formula was approximately—

$$f = 5 \cdot 08 \left(1 + \tfrac{1}{2} \frac{\text{minimum}}{\text{maximum}}\right).$$

This allowed $7 \cdot 62$ tons per square inch on steel for a dead load. Now, considering ordinary double-line railway bridges, the results given by this formula might be looked upon in two ways. If the fatigue of the material, according to Wöhler's experiments, was taken into account, and the dynamic action of the rolling load disregarded, then it fixed the working-stress as shown in column 4. If, on the other hand, impact alone were to be provided for, then the formula gave percentages to be added to the live load, as shown in column 5. The formula was also convenient because, taking Wöhler's experiments only into account, it gave a constant factor of safety. The results in column 5 showed that for plate girders

up to 100 feet span, an equivalent formula would be $1\frac{1}{2}$ live load + dead load, the unit stress being $7\frac{1}{2}$ tons per square inch. Mr. Gilbert.

1	2	3	4	5
Span.	Railway Commissioners, 1849. Increase of Deflection due to Velocity of Rolling Load.	Author. Proposed Allowance for Impact.	French Government Formula. Working-Stress.	Equivalent Increase of Rolling Load.
	Per Cent.	Per Cent.	Tons per Square Inch.	Per Cent.
10	..	25	5·60	46
30	32	15	..	45
48	14	14	..	..
60	..	13	6·04	42
100	..	10	..	..
120	..	..	6·40	40
264	Almost nil.	..	..	..

Mr. Walter Beer did not propose to refer further to the errors of the method of equivalent distributed loads except to say that in girders for which that method could be actually used, viz., girders of comparatively short span, the errors would be magnified; because in such girders the centre section was generally carried right through, so that there was an error of 20 per cent. in the weight of the flanges, or of about 12 per cent. in the weight of the whole girder. About 1895 he had made calculations similar to those made by the Author, of equivalent distributed loads for a load system composed of two Great Northern tender-engines and two Great Eastern tank-engines followed by two loaded coal-wagons. The curves obtained were not quite comparable with the Author's curves, because the engines were not quite the same, but they were very nearly comparable, and they very nearly agreed. Another comparison which might be of interest occurred to him. Some 6 years ago, when he was with the Great Western Railway Company, a Table of equivalent distributed loads was in use at Paddington, showing a curve for tank-engines, similar to the curve drawn by Mr. Farr but giving materially different results. He did not know on what system the Table in question was calculated, but it might be interesting to hear from anyone who remembered the calculations how the divergence arose. With regard to the question of the Author's proposed allowance for dynamic action and other secondary stresses, if it were desirable to adopt an empirical curve of the kind proposed, then the Author's curve might be correct; but if it Mr. Beer.

Mr. Beer. were undesirable, as he thought it was, that an empirical curve should be adopted without the matter being thoroughly threshed out first, exception might fairly be taken to it. The Author only touched on the question of dynamic action or impact and not at all on many other secondary stresses; he mentioned bad permanent way, but he did not mention the action of brakes, which often had a great effect on cross girders; nor did he deal with the side thrust of locomotives, and other well-known causes of secondary stress which had been discussed. On consulting the Paper referred to by Mr. Farr, he found that Professor Melan, after setting up the theoretical propositions, said that on the ground of his practical experience he did not consider the speed at which loads passed over bridges had the theoretical effect upon them. Mr. Turneaure in America had come to the conclusion that, whilst the speed at which a train passed over a bridge had no sensible effect on the deflection, vibrations increased the stresses in bridges by about as much as 50 per cent. This showed how investigators differed on the difficult question of secondary loading and how rash it appeared to be to accept, without exhaustive consideration, any empirical formula.

Sir Benjamin Baker. Sir BENJAMIN BAKER, K.C.M.G., at the request of the President, summed up the discussion. He said that, with regard to his own observations on the Papers, he really should not have attempted to intrude them, as he had had opportunities during the last 20 years or 30 years of expressing his opinions on the subjects dealt with, and he did not think they had varied much during that period. Mr. Cruttwell had referred to the book which Mr. Waddell had written on the same subject, and Mr. Bell had drawn attention to the fact that some of the conclusions of Mr. Waddell had been more recently discussed in America. He supposed Mr. Bell was referring to the fact that the Annual Convention of the American Society of Civil Engineers in 1899 took up the very subject which the Institution had been discussing the last two or three evenings, viz., the concentration of wheel-loads, and the question whether the results of fatigue should be taken into account in designing railway girders. As a matter of course, the discussion might be considered to a certain extent supplementary to that in America, and he suggested that any speakers who had not followed the American discussion should see what the views of the leading American bridge-engineers were on the important subjects under consideration. He had considerable sympathy with his old friend Mr. George Morison, who was certainly one of the most experienced and distinguished

bridge-engineers in the world, when he said that he had made elaborate calculations, taking into account certain wheel-loads on locomotives and certain rolling loads, for a bridge to last at least 50 years, and then within two or three years the type of locomotive which he had taken had been entirely altered, 30 or 40 per cent. had been added to it, and away went all those minute calculations. Mr. Morison suggested that engineers should agree upon some loads which should be taken to facilitate calculations and should be representative, not of a particular existent type of locomotive on a given railway such as the Board of Trade spoke of, but of what might be reasonably accepted as the heaviest rolling load which the railway might have to encounter in ordinary working during its life. It was obvious to all that the weight on a driving-axle, the distance apart of the driving-axles, and all such details, might vary within two or three years; and even the static weight would not be a measure of the load to a railway engineer who had studied the action of different locomotives, because he knew his bridges were punished very much more by a badly-balanced locomotive with six small wheels coupled running at high speed than it would be by an engine with a long wheel-base, a bogey in front, and a weight on the driving-axle perhaps 50 per cent. higher than the other. He agreed that it would be advantageous if the bridges on different railways had not to be designed for the various existing types of locomotives on the different lines as indicated by the Board of Trade rules, and if rolling loads might be accepted by engineers which facilitated calculation and provided a reasonable percentage of increase for the future. The beneficial influence of the dead load in the sense of inertia had been referred to by Dr. Brightmore and Mr. Bell, and the latter speaker had called attention to the different results of striking a thing with the anvil on it, or under it. Of course a great many of Wöhler's experiments, and of his own experiments, had nothing at all to do with "anvil" or dynamic action, but were simply slow bendings—sometimes 10 a minute, and sometimes faster or slower—by springs, without dynamical action. Therefore the questions of the anvil and of the dead weight did not come in at all; it was simply the question of the range of stress. On this point it was often said that in bridges and other structures the stresses were so far within the limit of elasticity that experiments of that sort on iron and steel strained beyond that limit did not apply. He had said 20 years or 30 years ago that he did not see how that was true. It would be so, of course, if the girder were an ideal structure

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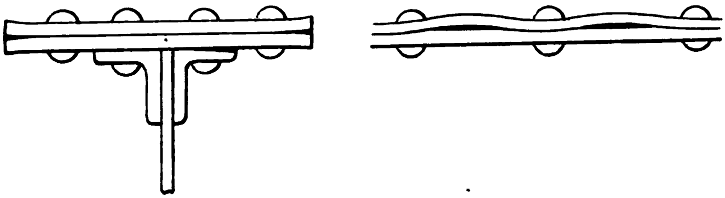
made of material subject to no internal strains and uninfluenced by changes of temperature or other contingencies, but in which the stresses were as calculated by the ordinary rules. If it could be said that an average stress of 7 tons per square inch on a given cross section was equivalent to a maximum unit stress of the same intensity, it might be so, but it was known that with all the contingencies of manufacture and maintenance that could not be. Nearly 40 years ago, after a discussion in that room on the Charing Cross Bridge,[1] when a great deal had been said as to the unequal distribution of stress because the pins were not in the line of the centre of gravity of the top and bottom members, he had written a letter to one of the technical papers saying that whilst he agreed the pins were wrongly placed, it seemed to him that too much was made of the fact, because there were so many other more important contingencies about that and other bridges. He had said at the time that the tie-bars were in two thicknesses, riveted together with rivets some feet apart, and that rust would get in between them and they would be bent and there would be cross stresses on those bars, raising the calculated stress of 4 tons per square inch to 8 tons or 10 tons. If the bridge were looked at now it would be seen that it was so; the diagonals at first, when straight, would have perhaps 4 tons per square inch stress; but now they were bent, with nearly an inch of rust between them, and they had at least double that unit stress. This was no solitary example, but a common contingency. The Lambeth Bridge bars, 1 inch thick, were bent $\frac{3}{8}$ inch by rusting, and the Wandsworth Bridge angle bars $\frac{1}{4}$ inch. In riveted girders there was oxidation going on between the plates (*Figs. 11*). If the rivets were close together the waviness was not as obvious as in the flat bars cited, but the bending stresses existed in as great a degree. There were all sorts of contingencies, such as the preceding, which tended to alter the stresses, however carefully a bridge might be designed, and the unit stress on the metal might easily be locally raised beyond the limit of elasticity, and therefore come within the range of Wöhler's and other experiments on repetition of stress and alternating stress. He ascertained experimentally a long time ago and had pointed out that in ordinary girders serious initial stresses occurred during manufacture. Taking for illustration the ordinary tee section (*Figs. 11*), with a couple of thicknesses of plate edge-rolled, the first thing to be done in manufacturing was to straighten the edge-rolled

[1] Minutes of Proceedings Inst. C.E., vol. xxii. p. 512.

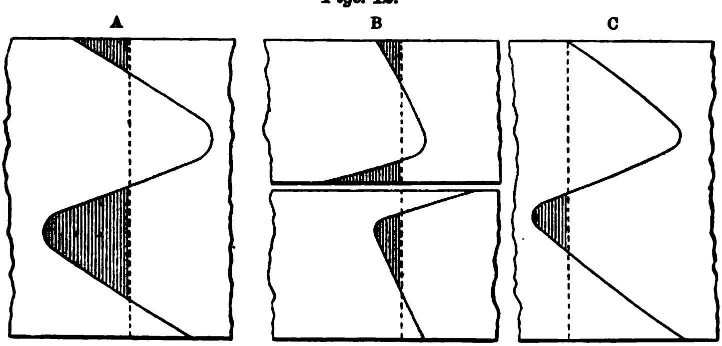
plates: that left stresses in them, and when the bridge was built those stresses remained. A, *Figs. 12*, was a plan of the flange indicating roughly the nature and intensity of the initial tensile and compressive stresses remaining in the straightened plate. To verify the existence of these stresses he had sawn plates longitudinally down the centre causing a readjustment of the internal Sir Benjamin Baker.

Figs. 11.



stresses as shown in B and a consequent lateral bending of both halves of a plate. Supposing now an average stress of 7 tons per square inch were put on the edge-rolled plates straightened cold, there would not be a uniformly distributed stress of 7 tons. What would be obtained would be more like that shown in C. If the plate had been cold-straightened edgeways to a considerable

Figs. 12.



extent, there would be an average of 7 tons per square inch over it, it is true, but there would be practically nothing at one edge and about 14 tons per square inch at the opposite edge. Having a diagram of the elongation of the material beyond the elastic limit the initial stresses could be calculated, or, as he had done, a flange plate could be taken after it had been cold-straightened, and cut up into slices longitudinally, and then it could be seen how much the different sections would curve when they were released from the couples which kept them in the straightened

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condition, after they had been cold-straightened. Or, as he had also frequently done, a plate which had been flattened cold could be planed on both sides, and the resultant curvature be noted. Supposing that the girder referred to were loaded with half dead load and half live load, then the range of stress would not be from 3½ tons or 7 tons per square inch throughout the steel-plate flange, there would be actual compression at some points and 14 tons tension at others. There would be all sorts of variations, and it would have to be admitted that in some part of the plate which was cold-straightened the range was more probably from 10½ tons to 14 tons. Wöhler's and his own experiments showed that a good steel plate would bear an infinite number of repetitions of stresses of that amount. There was another thing which engineers who had dealt with old bridges would see tended to a similar result, namely, the oxidation already referred to as going on between the plates, and consequent bending of the plates into a wavy line. There again it would be found that the range was not from 3½ tons to 7 tons, but very much the same as in the last case, from 10½ tons to 14 tons. It was for that reason, of course, that all engineers instinctively and by universal usage insisted on having ductile material for riveted girders, because it was not possible in the contingencies of work for any man to say that he had designed a bridge which was not liable to have stresses exceeding the limit of elasticity; but he could say, as the result of practical experiments in bridge-building, and as the results of the experiments of Wöhler, his own experiments and those of every man who had worked on the repetition of stresses, that such variations of stress might occur locally at different parts of the cross-section of a flange or tie-rod and go on for billions of times without breaking down the bridge, provided the material were fairly ductile and other things were right. It was hardly necessary to point out that the deflection of a girder afforded no evidence as to what the maximum stress on the steel might be, as it took no account of initial stresses, and would be practically the same in a steel girder whether the unit stress ranged from 3½ tons to 7 tons or from 10½ tons to 14 tons per square inch. Nor was it necessary to state that formulas for the working-stresses on bridges founded simply on Wöhler's experiments, and ignoring other practical conditions often of as much importance as the relative proportion of live to dead load, would lead to badly proportioned structures. More instructive than deflections were extensometer measurements taken at opposite edges of flange-plates, bars, and gussets under a rolling load, as, although they did not detect initial

strains, they measured the secondary stresses referred to by Mr. Stromeyer. Thousands of such measurements had been made during the past 25 years, and it was quite time that the results were summarized and that facts rather than speculations were placed before engineers. It was quite time also that the results of the past 50 years' experience, as regards bridge-failures, were summarized, for trouble with metallic structures rarely arose at the points indicated as the most severely strained by the ordinary methods of calculation. Many engineers would be astounded at the number of cases where, apart from initial stresses, good ductile wrought iron had stood stresses from live and dead load of more than 10 tons per square inch for years without signs of distress. In early American bridgework heavy stresses were common. Thus, in a Railway Commissioner's Report of 1872, it had been mentioned that a 66-foot bridge on the Erie Railway had broken down at last under an ordinary working-stress of between 13 tons and 15 tons per square inch; that others had failed with between 12 tons and 15 tons; that on the Boston and Albany Railway the working-stress on the vertical tie-rods of the timber bridges in five cases ranged respectively from 11·2 tons to 14·4 tons; from 9·7 tons to 12·4 tons; from 10·3 tons to 11·9 tons; from 8·7 tons to 13 tons; and from 10·2 tons to 12·2 tons per square inch; whilst 17 tons per square inch was a common stress on platform-bolts. Our own 50-year-old Britannia and Conway tubular bridges showed that with good material and more than ample rivet-area heavy stresses did not always induce signs of weakness. Parts of these bridges under dead and live load would probably be stressed to between 7 tons and 8 tons per square inch, apart from contingencies not included in the original calculations, such as temperature-stresses. The latter must be important, however, considering that the tube had a cellular top, and that the outside skin would at times be covered with snow at a temperature of 12° F., whilst the inner skin would be warmed by the hot gases and steam from passing locomotives. Again, the outside skin had been found heated by the sun to 125°, whilst the temperature inside the tube was between 70° and 80°; so, remembering that 12° variation of temperature was the equivalent of 1 ton per square inch stress, if movement was restrained, it was clear that stresses over the elastic limit must often have occurred with impunity in the case of these well-riveted old bridges. Observations with ordinary types of railway bridges had shown that 2 tons per square inch was not an unreasonable addition to make in respect of temperature when estimating the probable actual unit stresses Sir Benjamin Baker.

Sir Benjamin Baker. on members of a girder. That many disasters had not occurred to bridges from high unit stresses on the metal was due simply to the fact that engineers were fully aware that the elongation of iron and steel beyond the elastic limit was of paramount importance, although it seldom entered into their calculations. Consideration of *Figs. 12*, he thought, would show, firstly, that a logical statement of the probable maximum unit stress on a member of a girder could not be made without having regard to the diagram of elongation of the material—not merely up to the elastic limit, but up to the breaking-point—and secondly, that a large increase in the nominal stress from dead and live load did not necessarily imply a large increase in the maximum unit stress on the material. Thus, if C (*Figs. 12*) represented the actual varying unit stress under a nominal stress from dead and live load of 7 tons per square inch, then doubling the load would only increase the maximum unit stress 1 ton or 2 tons, and not 7 tons, because the heavily stressed portions of the flange would stretch, and the portions which under 7 tons were not stressed at all would carry perhaps 12 tons per square inch. Wrought-iron plates had small ductility across the grain, and he had found many fractures of web-plates and gussets due to the inability of the material to effect the equalization of strains referred to above. Again, his experience in gun-construction had enforced the same conclusions. A forged-steel gun was safe, and a cast-steel gun of the same kind of steel unsafe, not on account of modulus of elasticity or tensile strength, which might be the same in both guns, but because the elongation beyond the elastic limit was regular in one case and erratic in the other. In tests of 6-inch gun-tubes made at the Royal Arsenal at his suggestion, he had found that, where the steel was of a quality that admitted of a ring cut from the tube being stretched over a mandril about 2 inches, the calculated average unit stress on the tube when burst by cordite was 93 per cent. of the ultimate tensile strength of the material; whilst when, owing to irregularity in the ultimate elongation of the material, the ring stretched only about ½ inch, the corresponding percentage was reduced to 43 per cent. By the ordinary formulas for the strength of thick tubes, the percentage would have been 61 per cent., which was neither one thing nor the other, as might have been expected, since such formulas ignored the all-important element of elongation, regular or otherwise, beyond the elastic limit, and led to conclusions of little value to the practical man. A study of A (*Figs. 12*), he thought, would throw light on many practices, the result of experience of manufacturers,

such as testing guns, pitch-chains, and other things with proof loads 25 per cent. to 50 per cent. higher than the working-loads, so as to stretch the metal slightly and equalise initial strains in it. It also explained the irregularity in experimental results with long columns, and he had found that, whilst a column straightened hot stood 14·7 tons per square inch, a similar one straightened cold failed with 11·5 tons, as might have been predicted. In conclusion, he would remark that, whilst Wöhler's and other experiments on the effect of repetitions of stress on test specimens were invaluable in many respects, yet they afforded no royal road to bridge-design, for engineers had to take into account many other results of practical experience, and he still hoped that the bridge-engineers of three or four of our leading railway companies might combine and present to the Institution, for the benefit of their fellow members, the results of their experience in the maintenance and renewal of girder bridges. Sir Benjamin Baker.

Mr. Farr, in reply to the Discussion, desired to express his regret that he had been unable, from causes over which he had no control, to be present at any of the meetings. He had read with great interest and respect the very scientific remarks of Professor Unwin, with some of whose deductions and statements he was, however, from a practical standpoint, unable to concur. He agreed that the methods of typical locomotives and of influence-curves, with both of which he was well acquainted, were desirable in calculating lattice or open-framed girders; but he could not agree that they were more desirable than the method of equivalent uniformly distributed loads for calculating the strengths of plate girders of spans less than 100 feet, under the conditions specified in the first portion of the Paper. Professor Unwin referred to some difficulty in ascertaining the shearing stresses from the Tables, but there was really no practical difficulty at all; generally speaking, the webs of plate girders could not in practice be made as thin as they theoretically should be; and, consequently, if the loads per lineal foot in the Tables were used for the shearing stress, although they would be slightly (possibly 3 per cent. or 4 per cent.) less than the actual shearing stress, it would be found that, for practical reasons, the web-section would have to be made very considerably larger than was indicated by the tabulated load. Taking for example, as a rough calculation, a span of 60 feet with the suggested load of 2·46 tons per lineal foot, and assuming the load carried by two main girders, then the shear at the ends of each girder would be $\frac{60 \times 2 \cdot 46}{4} = 36 \cdot 90$ tons: this at 4 tons per square inch would Mr. Farr.

Mr. Farr. require a sectional area of 9·22 square inches, the depth of the web would be about 5 feet or 60 inches, and consequently the required thickness of web would be $\frac{9 \cdot 22}{60}$ = less than $\frac{1}{8}$ inch; whereas the least thickness of web for such a girder would be $\frac{3}{8}$ inch, or about two and a quarter times the required thickness. The French Government certainly did indicate the use of a typical locomotive for the design of girder bridges; but the Austrian and German Governments employed the method of equivalent uniformly distributed loads, and in America, also, it was in general use for designing plate girders, and by some bridge-builders for the chords of trusses. It was not intended to convey that the heaviest weight on an axle of any passenger engine on the Great Western Railway was 17·05 tons, but that that was the heaviest weight in connection with the heaviest engine. The one with 19 tons on an axle referred to by Mr. Elliott Cooper weighed only 82 tons, as against the 84·65 tons of the engine given in the Table. He entirely agreed with Mr. Inglis that the wheels of all vehicles intended for fast running should be accurately balanced, and in addition he would suggest that some method of centre coupling and buffer combined, automatic or otherwise, should be tried, preferably coupling the bogies instead of the carriage-bodies, as had been tried with success in Germany. If, in addition, one wheel of each pair were free to revolve on its axle, he believed that the ease and smoothness of running would be very marked and would enable locomotives to haul heavier loads or to attain higher speeds with the existing loads, while at the same time the wear and tear of the stock and permanent way would be decreased. He assumed from Mr. Dawson's remarks that that gentleman considered that travelling cranes were heavier loads than locomotives, and should be taken in preference to them in estimating moving loads on bridges; but before writing the Paper he ascertained from the leading cranemakers in this country the weights of the heaviest railway-breakdown cranes that had been built by them, and he worked out the loads due to them, with the result stated in the Paper. It should also be borne in mind that these heavy cranes travelled at rare intervals on the railways, that their influence as a factor needing to be considered was confined to the smaller spans, that they were always run at slow speeds, and that they were free from tendencies to increase the loads on the bridges due to factors *a*, *c* and *d* (pp. 3 and 4). The 20-ton hand-crane referred to by Mr. Dawson as used by him on the Chester and Holyhead line was not in existence when the Paper was written;

Mr. Farr believed it had only been used three times, and that it was soon to be converted into a steam-crane with considerable reduction of weight. Its present weight was less than that of the Great Northern tank-engine given in the Tables, and as, while travelling, the jib was lowered and rested on a wagon in front of the crane, the total weight being thus carried on seven axles, while its speed was limited to 15 miles per hour, he thought Mr. Dawson need no longer be uneasy about it. In the absence of definite information, he surmised that the other extraordinary 20-ton crane mentioned would probably be one used in a steel-works, armour-plate or gun-shop, and not a crane travelling on a railway with its load of 25 tons on an axle. He was pleased to note Mr. Yeatman's opinion that the loads proposed would very safely cover anything that could possibly occur, and he thought the chief thing to be aimed at in railway structures was absolute safety. The very small additional weight in the flanges caused by the peaked section in the centre was really hardly worth consideration, as the weight of the web and stiffeners, and of the cross girders and floor remained unaltered, and the extra weight would be quite inappreciable. It should also be borne in mind, as pointed out in Sir Guilford Molesworth's remarks, that the cost of a railway included many items in addition to that of the girders of underbridges. He agreed with Mr. Gribble that standardization of British bridge-practice was necessary if our engineers were to compete at all with foreign engineers, and he hoped that, as a result of the discussion, some steps would be taken by the Institution to bring about such standardization, not only in the matter of loads and allowable stress in members under various conditions, but also in regard to sizes of angles, tees and plates, and, as far as possible, in respect of spans and types of girders and floors. He did not think Mr. Cruttwell seriously meant it when he suggested that a percentage ought to have been allowed for the amount of load transferred from the weather side to the lee side by the pressure of the wind. This would entirely depend on the construction of the bridge, and on whether the train ran between the girders and so was wholly or partially screened, or whether it ran over the tops of the girders. This matter, as well as others which also affected the question, such as skew span, superelevation of outer rail on curves, etc., were best dealt with specially, according to circumstances of each case. Mr. Hudleston said that no evidence had been adduced to prove the proposition that owing to the limitations of the loading-gauge the weights of locomotives had reached a maximum, and he quoted Mr. Farr.

Mr. Farr. as an example a very heavy locomotive to a limited gauge the tank-engines built for shunting on the Central London Railway, but he did not say if this was the type of locomotive he considered suitable for high-speed passenger and goods traffic. Mr. Bell's remarks as to gauge appeared to refer to the distance between the rails, whereas the statement as to limitation of weight of locomotives referred to above applied to the loading-gauge; if there were no loading-gauge to conform to, then engines of the sizes and weights of American locomotives might be used in this country, and in that case very greatly increased moving loads would have to be provided for. There was not, however, much likelihood of the present loading-gauge being materially altered, as such a course would involve the reconstruction of large portions of the railways here; and as the largest and heaviest locomotives recently built in this country quite filled, if they did not slightly exceed, the loading-gauge, it was quite evident that, as stated in the Paper, any increase in weight must be accompanied by increase in length and number of wheels. He had made numerous tests of deflections of bridges over 100 feet span, and his experience agreed with that of Sir Guilford Molesworth, as he had found in nearly all cases that the load at rest caused quite as great deflection as when passing over at speed, and in some cases even more.

Mr. Findlay. Mr. FINDLAY, in reply to the Discussion, remarked that Mr. Gribble had criticised the method of strengthening certain bridges described in the Paper and had said that it would have been an easy thing, even in India, to add flange plates to the cross girders. Such a measure would offer little more difficulty in India than in England, and had been adopted where it was an appropriate course; but in the present case it would not have sufficed, the connection to the main girders being weak. Work of this sort could be dealt with on general principles, and it was not within the scope of the present Paper to offer the data necessary to form a judgment on the wisdom of the course adopted. As Mr. Robertson has pointed out, stringers had to be used, and it would appear desirable therefore to arrange them to the best advantage. To ignore their distributing effect would not prevent its being exercised. Mr. Hudleston asked for a formula for double-track bridges similar to that given in the Paper for single-track bridges. The formula desired was—

$$I = \frac{3\,b^3}{128\,n^4\,(a^3 + 2\,c^3 - 3\,a\,c^2)}\,I',$$

where $2\,a$, as before, was the span of the cross girder considered as

freely supported at the ends, and $2c$ the distance between centres of tracks. This formula provided for both tracks being similarly loaded in order to produce the maximum effect to which the ratio was referred. It was important to bear in mind that the assumption of a cross girder freely supported at the ends was rarely realized, even approximately, in practice. The length $2a$ between bearings must therefore be made that which would give the same deflection as the actual girder at the rail-bearer. This could only be approximately judged. It might perhaps be useful to express the formula in another way, which was applicable to cross girders carrying stringers in any position, viz.— Mr. Findlay.

$$I = \frac{b^3}{64 n^3 m} I',$$

where m was a multiplier for deflection, such that the deflection of the cross girder, as actually attached to the main girders, when loaded, at the point where the stringer was to come, with a weight W was $\frac{m\,W}{E\,I'}$, m taking the place of the factor $\frac{a^3}{3}$ in the formula given in the Paper. The multiple m could be obtained by direct experiment without great difficulty, and the uncertainty in regard to the curve of deflection of the cross girder would be evaded.

Correspondence.

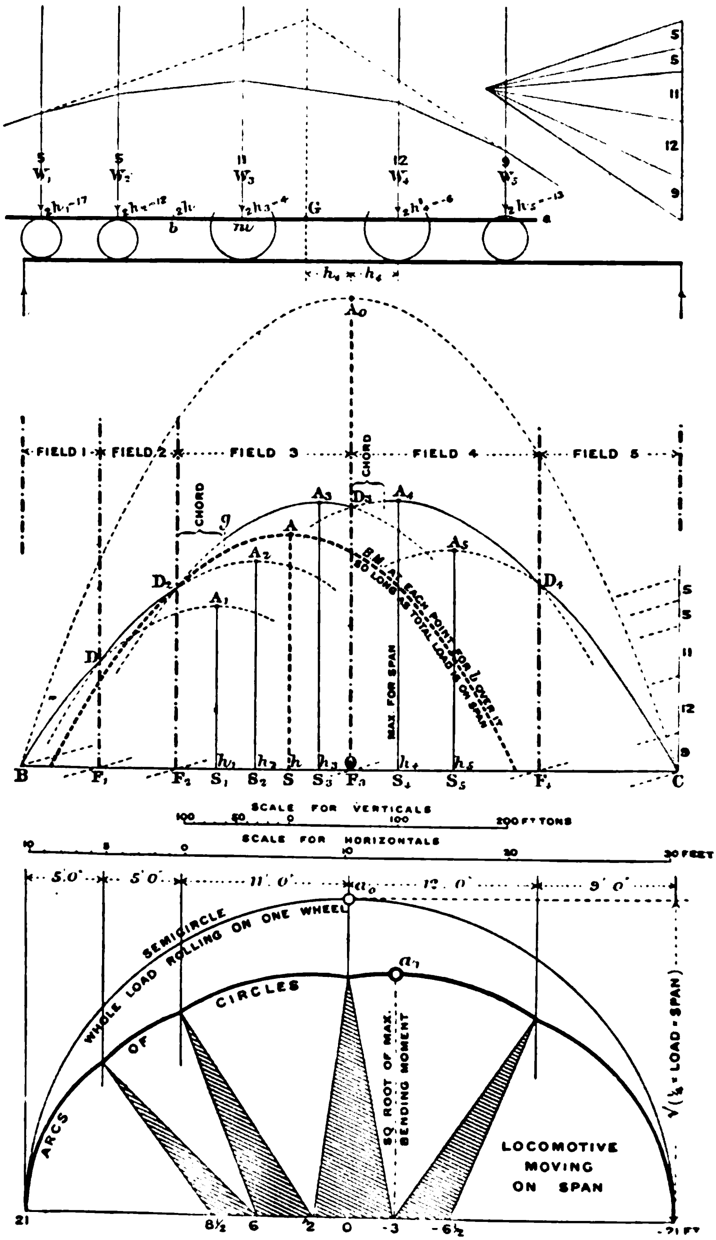
Professor T. Alexander, of Dublin, observed that about 10 years ago his partner, Mr. A. W. Thomson, now Professor of Engineering in Poona Science College, had worked out the equivalent uniform loads for a locomotive 50 feet long and weighing 80 tons, and almost the same as the Caledonian Railway locomotive and tender of that date. It might be interesting to quote the following results for comparison with those arrived at in Mr. Farr's Paper:— Professor Alexander.

Span	10	20	50	70	80	100 feet.
Load per lineal foot .	3·04	2·08	1·80	1·65	1·63	1·62 tons.

The Author must have been at immense trouble in calculating the maximum bending moments for the various load-systems in the tentative way in which he seemed to have gone about it. Professor Alexander had published exact rules more than twenty years

Professor Alexander.

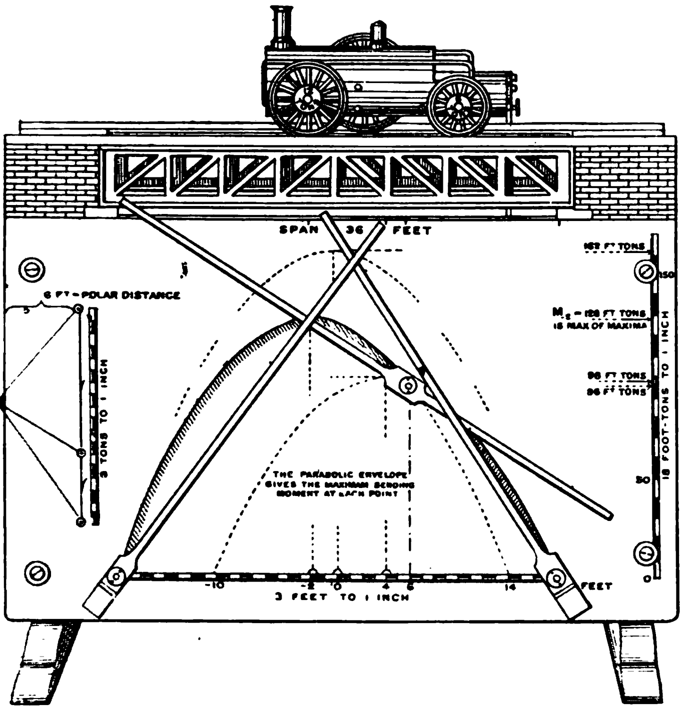
Figs. 13.



Professor Alexander.

ago.[1] Later on these had been reduced to a graphical process of drawing a series of parabolic segments with a single parabolic template, which was probably known, being quoted and referred to by Du Bois, Lévy, Hele-Shaw and others. He now published for the first time a much simpler graphical process with arcs of circles only. The upper part of the accompanying diagram (*Fig. 13*) showed a locomotive standing on a beam in the most trying position. The central part showed the set of parabolas drawn

Fig. 14.



with a common template, an arc of each dominating a field of the span, and the fields in order being in proportion to the loads on the wheels in order. The lowest part of the diagram showed, instead, arcs of circles struck from centres pricked on each side of the middle point of the span, in the same way that the wheels lay about the centre of gravity of the load, but at halves of those absolute distances. It was a diagram of the square root of the

[1] *Engineering*, 10 January, 1879.

Professor Alexander. maximum bending moment at all points of the span for all positions of the load-system. This diagram with arcs of circles was quickly and easily drawn, and it was equally easy to make a scale for it, because the semicircle standing on the span as diameter could be a like diagram to the same scale if the whole load were rolling on one wheel. The scale then was such that the half-span should measure the square root of a fourth of the product of the total load and total span. He also added a figure (*Fig. 14*) of a moving model with three laths turning on pivots and giving the instantaneous bending-moment diagram on a girder over which the two wheels of a locomotive rode. As the locomotive was pushed along the pole moved up and down at half the rate. The vectors from the pole were stiff wires passing through eyes in pivots fixed at the joints of the load line. As the pole moved up and down the pivots rocked about, being steered by the wires. These pivots were coupled to those of the laths, the laths being always parallel to the vectors, each to each. It would be readily seen that the corners of the instantaneous diagram, one under each wheel, swept out the parabolic paths painted on the face of the model. The scale for each instantaneous position of the laths was constant, as the polar distance was constant, and the whole was readily understood from Culmann's theorem alone. The model could be seen at the University or the College of Science, Dublin.

Mr. Moncrieff. Mr. J. M. MONCRIEFF remarked that no reference was made in the Paper to the most recent and most complete series of experiments yet made on the actual effects of train-loads on railway bridges, viz., those carried out in America by Mr. F. E. Turneaure.[1] These experiments had been made on twelve plate-girder bridges of spans varying between 25 feet and 80 feet, and on eleven truss bridges of spans varying between 100 feet and 200 feet, with trains running at various speeds up to 60 miles per hour. Mr. Turneaure had come to the conclusion that the effect on mean deflection of speed of application of the load was, alone, of no consequence in the spans tested (the increase in deflection from live load being due to vibration); and he had also pointed out that perhaps the most noteworthy feature in the results was the comparative uniformity in the maximum percentage added to deflection by vibration. He had found that the rates of vibration of the bridges for high speeds and large amplitudes agreed approximately with the rates of revolution of the locomotive driving wheels, and had showed

[1] Transactions of the American Society of Civil Engineers, vol. xli. p. 410.

quite clearly that the chief influence in producing vibration was the effect of the locomotive counter-weights, although considerable vibration was caused in some cases by loaded goods-wagons. In connection with extra stresses due to the condition of the permanent way, Mr. Moncrieff wished to draw attention to the advisability of making provision at the ends of the span of a bridge to prevent as far as possible the effect of the sudden change from a comparatively yielding bed of ballast to the rigid floor of the bridge. This sudden change must undoubtedly cause much heavier stresses in the endmost cross girders and rail-girders than in those which were nearer to the centre of the span, especially if the bridge was on the skew. In the case of a single-line bridge of 145 feet span, with a skew so great that one main girder was in advance of the other to the extent of 29 feet, and also in the case of a span of about 60 feet, he had endeavoured recently to minimise in the following manner the effect of the change from the soft embankment to the rigid cross and longitudinal girders. The rails on each bridge were carried on longitudinal sleepers 12 inches by 6 inches, and at the ends of the bridges these timbers were carried for a short distance beyond the steelwork and on to the soft ground behind the abutment, and were there packed up with ordinary cross sleepers laid close together and bedded on a layer of rubble. These bridges were both on so great a skew that the leading wheel on one side of a locomotive would strike the rigid bridge-end sooner than the leading wheel on the other side, and thus tend to make the engine rock and pitch; and to avoid this the longitudinal sleepers and their packing were carried out to form an end square with the line of railway. It was gratifying to him to find that the opinion he expressed in 1897[1] had been confirmed, viz., that the deflection of a particular bridge under a train at 60 miles per hour might very possibly be no more, or even less, than when the train was going dead slow, and there was probably for any given bridge some particular speed at which a train would produce its maximum effect. This was quite in accordance with the Author's observations of vibration in the case he had described, and it had also received corroboration in Mr. Turneaure's experiments. He thought the Author had hardly laid sufficient emphasis on the prejudicial influences of locomotive balance-weights, and a study of Mr. Turneaure's tests appeared to warrant this opinion. With regard to the Board of Trade regulations for permissible stresses in steel and iron, he believed that Mr. Moncrieff.

[1] Minutes of Proceedings Inst. C.E., vol. cxxx. p. 181.

Mr. Moncrieff. it would be difficult to find a competent bridge-designer who paid any attention whatever to these relics of antiquity except to keep below the limit of stress in cases where the Board of Trade had jurisdiction, although a higher stress in certain cases might be perfectly safe. As a general rule, however, in railway bridges of 100 feet span and under, the permissible stress was far below the limit fixed by the Board of Trade, and especially so in the shorter spans and in cross and longitudinal girders. In view of the importance of the subjects of proper loads and permissible stresses he again suggested that the Institution should take up the question and appoint a Committee to collect information and to present a report in the same way as it had done in the case of the thermal efficiency of steam-engines. It was not to be expected that such an enquiry and report would be accepted as at all final or conclusive, but it would certainly tend to place the matter on a much firmer and better-understood basis. That there was some necessity for this was well known to those who made a special study of bridge-design, and was also testified to by the extraordinary and often wasteful designs published in technical papers and found under construction in English bridge-yards. It was surprising how little attention had been paid to these important subjects by the Institution in the past. The Author deserved the thanks of the profession for the great labour which he had expended on the determination of the distributed loads equivalent to so many British locomotives, but it was not clear that these loads were such as would cover "all stresses" as claimed by the Author. They did not appear to cover the shearing stresses, but only the bending moments, and were therefore only applicable to the design of the flanges of girders. It was of course well known that the maximum bending moment might be produced by an equivalent distributed load which would not produce the same maximum shear as the actual load-concentrations, particularly in the case of the central portions of the girders. This being so, it would probably be preferable to design girders to carry an equivalent load composed of a uniform load combined with a concentrated load, as proposed by Mr. Geo. H. Pegram in 1886[1], and it was interesting to note that the entirely uniform loads arrived at by the Author were closely approximated to by a load given by the formula—

$$\left(1 \cdot 6 \text{ tons} + \frac{32 \text{ tons}}{\text{span}}\right) = \left\{\begin{array}{l}\text{Uniform average load per lineal foot for}\\ \text{design of flanges.}\end{array}\right.$$

[1] Transactions of the American Society of Civil Engineers, vol. xv. p. 474.

In accordance with Mr. Pegram's suggestion, this would be the load used in the design of the flanges, while the web would be designed to carry a load of 1·6 tons per lineal foot, headed by a concentrated load of 16 tons. It would be noticed that the average load given by the above formula would produce exactly the same bending moment at every point as a uniform load of 1·6 tons per lineal foot, combined with a concentrated load of 16 tons. This method of estimating the equivalent loads was certainly a more rational one than that adopted by the Author, as would be apparent on considering a specific example. For a span of, say, 30 feet, the Author's equivalent load per lineal foot was 2·63 tons; this would produce a maximum shear at the centre of span of only 9·863 tons, which was obviously too low. If the uniform load of 1·6 tons per lineal foot, combined with a concentrated load of 16 tons at its head were used, the maximum shear at the centre of the span would be 14 tons, which would certainly be nearer the truth. For instance, the shear at the centre of a 30-foot span caused by the tank-engine of the Great Western Railway, assuming that there were 16 tons on each of two axles 7 feet apart and 15 tons on the remaining axle 8 feet from the central axle, would be 12·26 tons, or more than 24 per cent. greater than the shear calculated from the Author's value of the equivalent uniform load. Again, taking a span of 45 feet with the same engine, the actual shear at the centre of the span would be 16 tons, while the Author's load of 2·32 tons per lineal foot would produce a shear of only 13·05 tons. The concentrated load of 16 tons, together with a uniform load of 1·6 ton per lineal foot, would produce a shear of 17 tons at the centre of a 45-foot span. He would suggest that a load of 1·6 ton per lineal foot, combined with a concentrated load of 16 tons should be used in preference to the entirely uniform loads proposed by the Author. It was difficult to reconcile the Author's recommendations as to allowances for impact, etc., with the records of experiments, and the values given did not appear to be at all sufficient. Mr. Turneaure found that the increase in deflection (or in flange-stress) due to vibrations caused by locomotives running at speeds varying between 40 miles and 50 miles per hour was likely to range between 40 per cent. and 50 per cent. for bridges of spans varying between 25 feet and 50 feet, diminishing to about 25 per cent. in the case of spans of 75 feet. These values were far higher than those proposed by the Author, and it was to be noted that they were obtained with the track in good condition in every case. The allowances for impact, etc., on cross-girders and rail-girders Mr. Moncrieff

Mr. Moncrieff. given by the Author appeared to him to be far below what might be reasonably expected in actual work. The maximum loads calculated by the Author, exclusive of any allowance for impact, etc., if taken as for bending moments only, were, however, matters of fact and not of opinion, and were likely to be of great use to bridge-designers.

Mr. Roche. Mr. EDWARD ROCHE observed that it was stated in Mr. Farr's Paper that Professor Melan, after exhaustive consideration of the question, concluded that moving loads on bridges should be increased by a percentage varying between 80 per cent. for a 6-foot span and 30 per cent. for a 100-foot span, to allow for stresses due to impact and other causes; while the Author himself from practical observations estimated that the increase should vary between 30 per cent. and 10 per cent. for the same range of span. This seemed to be a very wide discrepancy between the results of theory and practice. Taking, for instance, a very common span for public-road bridges, viz., 40 feet, this would mean, according to the Author's diagram, that the allowance for impact, etc., would be close on 15 per cent., while according to Professor Melan, the increase for the same span would be approximately 37 per cent.; in other words, about $\frac{1}{4}$ ton per lineal foot in the former case and $\frac{3}{4}$ ton in the latter. This difference of $\frac{1}{2}$ ton per lineal foot (which increased as the span decreased) would cause a considerable increase in the strength, and therefore in the cost, of a very common type of girder. He agreed with the Author that now would be a favourable time for the Board of Trade to draw up amended rules for the design of girders; but such rules would in his opinion be very unsatisfactory if they were based on uncertain data as to what allowance should be made for impact and other causes. It seemed to him therefore that the first duty of the Board of Trade should be to institute careful inquiries into this subject, and to obtain if possible some fairly definite result as to the proper percentage to be added for the stresses due to impact, etc. Tables then drawn up for uniformly distributed loads over different spans would be entirely satisfactory.

Mr. Saner. Mr. J. A. SANER remarked that it had always appeared to him—although he had had very little experience of bridges subject to such rapidly-moving heavy loads as those under consideration—that the greatest stresses would occur when a heavy fast train passed on to a bridge with the brakes either fully or partially applied. The effect, as felt by passengers, of a sudden or severe application of the brakes, was known to everyone, and he would like to ask the Author whether any experiments had been carried out to ascertain

the stresses produced by this on the girders, or whether he considered the allowances mentioned in the Paper sufficient. Although the horizontal stresses, due to what might be termed the "clawing" action of the locomotive with a heavy train behind it in motion, might be so slight as to be absorbed by the metals, and give a practically vertical application of the load on the main girders, it was evident, he thought, that when the brakes were on a large proportion of the weight was carried on "slides" instead of "rollers," and that the horizontal stresses were reversed, and increased up to a certain point, depending on the coefficient of sliding friction. At the same time there was violent "jumping." This was a point he had often wished to bring before engineers responsible for railway bridges, and he hoped Mr. Farr would state the views generally held by them, and their reasons if such stresses were considered to be of no importance. Mr. Saner.

Dr. Bindon Stoney wished to draw attention to the fact that some years since the question of the abnormal stresses produced in short railway girders, whether main or cross girders, had been fully thrashed out, and practical rules and Tables had been given for finding the extra loading to be adopted in calculating their strength.[1] The effects of engine-oscillations, boiler-trucks, wind, snow, etc., were fully gone into, and although somewhat heavier engines might be now in use, the method and principles of estimating these abnormal loads and their effects on short girders remained the same. With reference to Mr. Findlay's formula, which the Author suggested would enable the designer of a railway bridge to reduce the load on a cross girder to any desired fraction of the axle-load immediately over that girder, he would caution young engineers that, though formulas might be, and frequently were, extremely valuable for the purpose of giving clear physical conceptions of stresses and strains, yet a very small error or alteration of line in the workman's method of construction, or in the method of riveting up or connecting the longitudinal rail-bearers with the cross girders, might completely vitiate the outcome of theoretical calculations and cause damage not only to the girder itself but to the reputation of the engineer who designed it. Dr. Stoney.

Mr. Edmund Wragge remarked that the statement as to bridges in Canada, which Mr. Farr referred to as now being strengthened owing, as he said, "to want of knowledge on the part of the designers," and which he seemed to think had "become Mr. Wragge.

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[1] "Theory of Stresses in Girders and Similar Structures," chapters 23 and 27. Longmans, Green & Co., London.

Mr. Wragge. obsolete in a short time," was hardly warranted by the facts. Those bridges had been built between 40 years and 50 years ago, and the rails then laid upon the Grand Trunk Railway had weighed 56 lbs. per yard and had been considered ample to carry the load for many years to come. Not only had the weight of the locomotives increased, however, but the goods wagons had increased in weight from 10 tons, with a capacity of 10 tons, to 14 tons, with a capacity of 30 tons; so that the rails with which the main lines were now being laid weighed 79 lbs. per yard. He did not think that under such conditions any rule now laid down by the Author would necessarily hold good for 40 years or 50 years to come. The Author might possibly not be aware of the specification for bridges adopted and used for the past 8 years by the Chief Engineer of Government Railways in Canada, which he thought might repay perusal by engineers interested in bridge-construction, providing as it did for the various strains which it permitted upon the different parts of several kinds of construction, and also for the rolling load applicable to various spans, the shorter spans of course having to bear a heavier rolling load per lineal foot than the longer, while a panel load in addition was to be considered in large spans. There was a copy of the specification in the Library of the Institution, as well as a copy of that by Mr. Theodore Cooper, so very generally used by engineers in the United States. In regard to locomotives being badly balanced, he might mention a case which had come under his cognizance in Canada. Control had been lost by the trainmen of a heavy goods train on a long incline falling 412 feet in 4 miles, and before the train had left the rails, which it had done within a few hundred yards of reaching the foot of the incline, a great number of rails had been broken (which had been eventually the cause of the derailment); and he had found upon examination, and upon measuring the distance of the breakages apart, that it corresponded exactly with the length of the circumference of the driving wheels of the engine, upon which had been placed a heavy counterbalance weight, to which he attributed the damage done. This had taken place between 20 years and 25 years ago, and the locomotive had eight wheels coupled and had been known as the "Consolidation" type of engine.

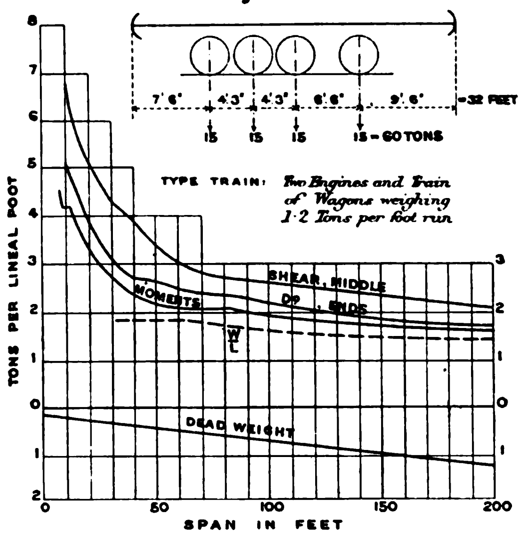
Mr. Zachariasen. Mr. L. S. Zachariasen thought that Mr. Farr's Paper might perhaps be divided into two parts, according to the more or less debatable character of the subjects dealt with. The effect of the various loads on the axles of engines and wagons, considered as mere weight, left but little room for argument; but it was different when the effect of these same loads moving at speed, and the

provision to be made for it, either by adding a percentage for impact, or by altering the permissible stresses per square inch on the material in the various parts of bridges, or possibly by the combination of both methods, was taken into consideration. With regard to the first subject, there would probably be no insurmountable difficulty in the way of agreeing upon a standard type train, which would cover the effect of all actual engines and vehicles in use in the United Kingdom at the present time, with what might be decided upon as a proper margin for probable increase of weights in the future. The adoption of such a type train would at least ensure a common basis for calculating the strains of bridges of any span, and would greatly help to remove anxiety as to the injurious effect of certain engines on any bridges over which they might have to pass. Diagrams similar to those contained in the Paper, giving the equivalent uniformly-distributed loads per foot run of any span, might be worked out once and for all for the accepted type train. Such diagrams had been in use for many years in this country, and perhaps more systematically on the Continent and in America, and had been found most convenient. It would have added considerably to the value of the Paper if curves had also been drawn in the diagrams to represent the shearing forces at the ends and middles of the different spans, for the engines for which the curves for bending moments had been drawn. While the latter were being worked out it would have been a comparatively small matter to add the former, and if the Author had the original diagrams by him, he might, perhaps, be willing to act on this suggestion, the more so as the equivalent uniformly-distributed loads for the maximum shears differed very considerably from those for the maximum bending moments, and the various engines would give relative results not always in accordance with what might be expected from a glance at the curves for moments. A diagram was appended showing the three curves, *i.e.*, for bending moments and shears at ends and middle of span, for the Government of India type train (*Fig. 15*). He was aware there was a supposed difficulty in arriving beforehand at a sufficiently accurate estimate of the dead weight of any particular bridge, and on this ground some engineers were in favour of dismissing the dead weight from direct consideration. However successful such a method might have proved in the practice of a particular individual, it was not likely to commend itself to engineers generally. When the proposed rolling loads, the nature of the flooring and permanent way, and the permissible stresses on materials were known, there was no difficulty in preparing a simple formula which would give

Mr. Zachariasen.

Mr. Zachariasen. the dead weight of any span with an accuracy quite sufficient for preliminary estimates and the calculation of the strains in the proposed structure. It was necessary, of course, to use slightly different figures for deck and through bridges, and in the case of small spans to make some allowance for plate girders against triangulated girders. A line showing approximate dead weight per lineal foot of "through" spans was shown in the diagram of rolling loads (*Fig. 16*). With regard to the Author's method of preparing the diagrams accompanying the Paper, and to their accuracy and utility, the ordinary use of such diagrams was to facilitate the calculation of strains in bridges of insufficient importance to

Fig. 15.



warrant the more exhaustive treatment which was due to works of greater magnitude. For this purpose the diagrams were quite sufficiently accurate, if properly prepared and intelligently used. For the exact comparison of the relative effects of different types of engines, wagons, &c., the true funicular curves might be necessary. Owing to the circumstance that the parabola coinciding with the centre of the funicular curve for a certain train did not coincide with it at all points, it had been suggested that the latter curve should be drawn for each bridge. It was not easy to see that any greater general accuracy would be attained by this extra trouble. It was true that the parabola generally was somewhat flat at the haunches as compared with the true funicular curve

Mr. Zacharіasen.

of most engines, and that therefore the strict use of it might result in undue weakness of the girders at these points. It must, however, be borne in mind that, for practical reasons, material in excess of that theoretically required was generally provided at these particular parts. He had in special cases used the following expedient in order to arrive readily at a result somewhat more in accordance with the funicular curve than the parabola drawn through its centre:—At a certain height above and parallel to the base-line was drawn a second line; on it a parabola was erected, the final line of which was drawn down to the end of the original base-line, as in *Fig. 17*. The best height of the second line above the base depended on the distribution of the weights of the type train, and varied generally between 10 per cent. and 20 per cent. of the centre ordinate. It was shown at 20 per cent. in the diagram, and the deviations at several ordinates were given in per cent. over the ordinary parabola. Although there was frequent necessity for strengthening the cross girders and rail-girders of old bridges, this was hardly ever necessary with the main girders. He had had considerable experience in investigating the strength of old structures, and quite agreed that, as a rule, the cross girders and rail-girders suffered more than the main girders. This was due, perhaps, to the difference between the more modern method of calculating strains from the actual axle-loads as compared with the old way of taking the uniform distributed load due to the weight of the train divided by its length. The difference affected the cross girders and rail-girders more than the main girders, as would be noted by reference to the diagrams (*Figs. 15* and *16*), where lines showing the weight of the train divided by its length had been added. The difference for main girders between 40 feet and 200 feet in span was thus practically constant, viz., about 15 per cent.; whereas for the cross girders it amounted to 37 per cent. for 16-foot bays, 60 per cent. for 11-foot

Fig. 16.

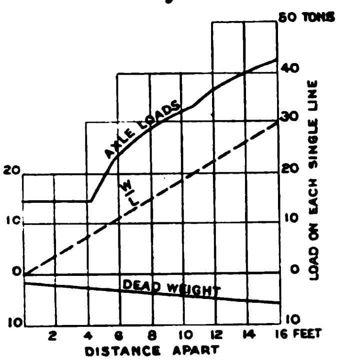
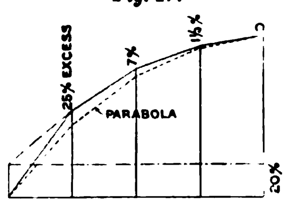


Fig. 17.



Mr. Zachariasen. bays, and 90 per cent. for 8-foot bays. The question of the failure of cross girders at their attachments to the main girders was an important one, but was perhaps a subject somewhat apart from Mr. Farr's Paper on moving loads, being rather a matter of detail design. With regard to the second or more debatable part of the Paper, the system of laying down elaborate rules for the design of bridges, which obtained in many countries, should secure theoretical uniformity of strength in all bridges designed in accordance with the particular rule in operation, which might be highly desirable where the traffic was fairly uniform. Where this was not the case, however, it must result, on the one hand, in some, perhaps not very considerable, extravagance in the case of bridges subject to light and infrequent traffic, or, on the other hand, in what might be far more serious, viz., deficient strength of those subject to the enormous traffic near busy centres. It was perhaps better practice to leave considerable latitude to the engineer for exercising his judgment as to the necessities of each particular case, when of any importance, and to provide for it according to circumstances. This would probably enable him to obtain a higher degree of efficiency at a moderate cost than would be possible where hard-and-fast rules were laid down for the treatment of all cases alike. The Government of India had laid down fairly complete, simple, and practical rules for a type train, wind-pressure and permissible stress per square inch of material. There was, however, one curious anomaly. The regulations provided that stresses due to a moving load should, in all cases, be doubled and added to those due to the dead load, except for the upper and lower booms of triangulated bridges, where the stresses due to the moving load might be multiplied by 1·5. The result of this was that with a span of 60 feet, for instance, the booms of a plate-girder might only be stressed to 5 tons per square inch, whereas the more, or perhaps less, fortunate triangulated girder might be stressed to 6·4 tons. In these figures steel was assumed to be the material, and only dead and rolling loads were included; the inclusion of wind-pressure, however, would not have any considerable influence on their ratio at this length of span. The Indian rule of doubling the strains due to the live load, adding the dead load and dividing the sum by a coefficient varying with the material used, was a simple one, and worked well in practice. By modifying the coefficient of the permissible stress per square inch for dead load, there was a ready means of providing for a lighter or a heavier structure, according to local requirements; either being capable of carrying the type train without risk of over-straining any part,

but the heavier bridge being capable of performing the duty much more frequently than the lighter one. He had used a somewhat similar formula for a number of years and had always found it very satisfactory in its results. Even on this subject there were points of practical unanimity, for instance, that the effect of a rolling load was very different from that of the dead weight of a structure. In making provision for this difference, the results arrived at by the various recognised means were not very dissimilar, nearly all of them taking into consideration in one way or another the proportion of live to dead load. Thus it was generally agreed that a large bridge with a considerable dead weight in proportion to the rolling load might be stressed with perfect safety to an extent which would be most undesirable in a smaller structure. The design of a bridge was, after all, not an entirely theoretical problem, capable of exact solution; there were so many practical considerations, often almost opposed to the theoretical requirements, that there did not appear to be any great necessity for attempting extreme accuracy in calculations. After the various methods had been tried and their results compared, it was generally recognised that the simplest was as good as any for practical work; true economy and efficiency of a bridge were dependent on the practical knowledge of the designer quite as much as, if not more than, on his indulgence in highly complex mathematical problems. Mr. Zachariasen.

Mr. FARR, in answer to the Correspondence, desired to say that he was acquainted with Professor Alexander's method of parabolic segments; in fact, a few of the diagrams were worked out by that method, and it had been his intention to use it throughout. He had found, however, that, no doubt owing to his unfamiliarity with the method and his incapacity to grasp the principle thoroughly in all its applications, he could work out the diagrams by the tentative process referred to by Professor Alexander in less time, with results which, if not mathematically exact, were at least sufficiently accurate for the purpose in view. As there were some thousands of diagrams he had decided to use the method with which he was most familiar. He would have much pleasure in studying the much simpler graphical process with arcs of circles now brought forward by Professor Alexander. The moving loads suggested were, as indicated on the diagrams, intended for stresses in the flanges only; the shearing stresses for any required span could be readily obtained from the diagrams of the wheel-bases and weights of locomotives given. The recommendations as to the amounts to be allowed for impact and the other factors causing Mr. Farr.

Mr. Farr. increased deflection of girders were based upon the results of a very large number of observations of actual deflections of the girders of railway underbridges, made during the past 20 years. One point, perhaps not quite sufficiently clearly stated in the Paper, was that the moving loads were those for the stresses in the flanges of girders of uniform strength only, and that, if girders of the smaller spans were designed of uniform section, then the moving loads to be taken would, of course, be smaller in amount. He would endeavour to find time to work these out, and also the shearing stresses for the different locomotives, as suggested by Mr. Zachariasen. It had been his intention to embody these in the original Paper, but, owing to the great labour involved, he had been unable at the time to undertake it.

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13 February, 1900.

JOHN CLARKE HAWKSHAW, M.A., Vice-President, in the Chair.

The discussion on the Papers by Messrs. Farr and Findlay on "Moving Loads on Railway Underbridges" and "The Floor System of Girder Bridges" occupied the evening.

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20 February, 1900.

SIR DOUGLAS FOX, President, in the Chair.

The discussion on the Papers by Messrs. Farr and Findlay on "Moving Loads on Railway Underbridges" and "The Floor System of Girder Bridges" was continued and concluded.

27 February, 1900.

SIR DOUGLAS FOX, President,
in the Chair.

(*Paper No. 3225.*)

"Corrosion of Marine Boilers."

By JOHN DEWRANCE, M. Inst. C.E.

THE introduction of water-tube boilers and the use of continually higher working pressures have rendered the subject of this Paper of increasing importance. Corrosion in marine boilers is principally due to the chemical union of the iron of the plates and tubes with oxygen dissolved or mixed with the feed-water, the product being an oxide of iron.

It is stated in standard chemical dictionaries and text-books, that there are three oxides of iron:—

The ferrous oxide or monoxide	FeO
The ferric oxide or sesquioxide	Fe_2O_3
The magnetic oxide	Fe_3O_4

The first two of these are undoubtedly the minimum and maximum proportions in which iron and oxygen combine, but between these limits iron will combine with oxygen in any proportion. The following Table gives a sufficient number of analyses of oxides of iron to establish this:—

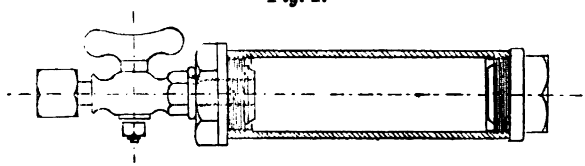
Oxides of Iron.	Iron.	Oxygen.
Ferrous oxide or monoxide of iron FeO	77·77	23·23
Oxide from superheater, two specimens	76·28	23·72
Oxide from superheater roasted in air for one hour	73·10	26·90
Oxide further roasted in oxygen for one hour	72·30	27·70
Oxide further roasted in oxygen for two hours, hotter	70·78	29·22
Furnace scale	74·66	25·34
Theoretical magnetic oxide Fe_3O_4	72·41	27·59
Ferric oxide or sesquioxide Fe_2O_3 also called peroxide and commonly known as rust	70·00	30·00

If the hydrated sesquioxide is in contact with iron, and there is no oxygen available, it will take up more iron, and under suitable circumstances will be gradually converted into monoxide, which, however, would rapidly return to sesquioxide if the boiler were opened and the oxide were exposed to air.

Iron and steel will not unite with the chemically combined oxygen of water to any considerable extent below a red heat.

To prove this a steel tube was bored out and was fitted with caps and a cock, as shown in *Fig. 1.* The air was exhausted very carefully, and the tube was about half filled with distilled water, and was put into a boiler that carried 300 lbs. per square inch pressure for 74 hours, and lower pressures down to 130 lbs. per square inch for 52 hours. At the end of this period the quantity of water was exactly the same and perfectly colourless, and the tube showed no sign of corrosion. On the other hand, it is only necessary to leave distilled water in a bright iron vessel for a few minutes to discolour it with sesquioxide of iron, showing how rapidly distilled

Fig. 1.



water will corrode iron when the water has been exposed to the air. A similar tube was filled with sea water, from which the sulphate of lime had been precipitated to prevent it from causing a scale. The air was exhausted, and the tube was placed in the same boiler for the same period side by side with the first tube. In this case also the water was as bright and colourless when taken out as when put in, but on standing it discoloured, showing that a small quantity of hydrochloric acid had been produced, forming a soluble protochloride of iron that was converted into oxide of iron as soon as the water was exposed to the atmosphere and dissolved air. This cause of corrosion was, however, so limited that careful examination of the tube did not disclose which side of it was exposed to water. It must, however, be borne in mind that the tube was not under the same conditions as the heating surfaces of a boiler, as there was no chance of over-heating.

Setting aside fatty acids, which ought never to be admitted to a boiler, the only cause of corrosion which can to any extent affect

the part of the internal surface of a boiler that is not liable to be overheated, is the air dissolved in the water before it enters the boiler. To establish the effect of air corrosion relatively, a number of careful tests were made by boiling in iron dishes, and to establish uniformity of aeration a glass tube was caused to deliver air into the solution. The most important results are given in Table I.

These tests were all made for 4½ hours.

TABLE I.—CORROSION PRODUCED UPON IRON DISHES IN WHICH DIFFERENT SOLUTIONS WERE BOILED FOR 4½ HOURS.

	Oxide produced. Gram.
Distilled water	0·1298
" " with lime	0·1273
" " " sodium carbonate	0·0083
" " " zinc chloride	0·1398
" " " " " and zinc oxide	0·1534
Sea water	0·1366
" " with lime to decompose the magnesium chloride	0·1583
Sea water with zinc sulphate	0·2121
" " rendered alkaline with soda	0·0855
" " Magnesium sulphate	0·3242
" " Magnesium chloride	0·2995
" " Calcium chloride	0·2694
" " Sodium chloride	0·2530

It will be seen that while pure distilled water gave 0·1298 gram of oxide, sea water gave only 0·1366 gram. The addition of lime made practically no difference to distilled water, but it made the sea water more corrosive.

Air does not corrode very much more when dissolved in sea water than it does when dissolved in distilled water. It is therefore necessary to seek another cause to account for the rapid deterioration and pitting that occurs upon heating surfaces. It is beyond dispute that the sides of furnaces opposite the fire and the tube plates and the hottest tubes are liable to be pitted, and generally to suffer most from corrosion. In water-tube boilers steam is most rapidly generated in the tubes most exposed to the fire. Generally, boilers with forced draught suffer specially, and the Author attributes the pitting and wasting that occur on the inside of heating surfaces to the action of sea water. It is probable that it was this second kind of corrosion which led to the condemnation of the marine superheater, the salt water being carried up by priming. It has been attributed to the property that iron and steel possess at high temperature of taking

the oxygen from steam and liberating the hydrogen. This reaction has long been known to chemists, and was commercially introduced for the purpose of protecting iron articles from corrosion by the late Prof. Barff who exhibited many specimens of it in the Paris Exhibition of 1878. The Author has used the process for 20 years, and specimens exhibited show the magnetic oxide coating produced by a current of red-hot steam passed over the articles in a red-hot oven. Specimen 11 was plugged at the end by a zinc disk and projected into the oven. When the heat attained was sufficient to melt the zinc, the specimen was removed, and, though it had been in the oven several hours, the coating of oxide was still transparent, showing that the action does not proceed rapidly below the red heat. Specimens 12 and 13 are a portion of a superheater through which steam has passed at a red heat for several years of intermittent working. The oxide may be seen adhering firmly to the iron. Specimens 14, 15, and 16 are from a superheater of a Babcock boiler that has been in use for some months. This tube is of steel, and the oxide is adherent. These superheaters are flooded with water while steam is being raised.

It must also be remembered that, as land boilers and superheaters do not suffer in the same way as marine boilers and superheaters, the action cannot be due to the steam, which is the same in both, but must be due to the salts contained in sea water (Table II).

TABLE II.—ANALYSIS OF SEA WATER.

	Grains Per Gallon.
Calcium carbonate	9·79
Calcium sulphate	114·36
Magnesium sulphate	134·86
Magnesium chloride	244·46
Sodium chloride	1706·00
	2209·47

It is generally accepted that when sea water is evaporated until it crystallizes, it becomes acid, and hydrochloric acid is commercially produced from magnesium chloride in a current of steam. Now the plates or tubes where the fire impinges most fiercely are known to attain a temperature far in excess of the temperature of the water in the boiler, even when there is no scale. In such circumstances the water cannot be touching or completely wetting the steel; and if the phenomenon of rapid boiling is observed closely, it will be seen that next to the heating surface there is

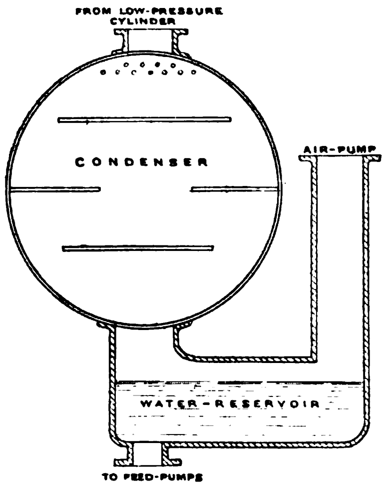
froth, not water. The water enveloping the steam is dashed against the steel and is evaporated to dryness in rapid succession, and each time this occurs with salt water the crystallizing point is reached, and a microscopic quantity of acid is produced right on the surface of the steel. If this theory of corrosion due to frothing is accepted, it is easy to understand the pitting of heated surfaces of metal. Furnace scale is rolled or squeezed into the surface in the course of manufacture and is removed by boiling. A cavity is begun where the metal is thinner and transmits the heat more freely. Steam bubbles keep the water from the inside of this cavity, and the circulation does not tend to wet it, being shielded from the current of water by the surrounding projections, which are constantly being augmented by the oxide of iron thrown out from the corrosion of the cavity. Whenever water enters the cavity a small explosion occurs, expelling the water and leaving a small quantity of chlorides, which, on being evaporated to dryness, give off a good deal of their hydrochloric acid to combine with the iron during the moment that intervenes before more water enters. Corrosion proceeds at an ever-increasing rate in the cavity, which grows in all directions, until it presents the familiar pitted appearance. To prevent this action something might be done by freeing the surface from furnace scale. Having dealt with the causes of corrosion it is now proposed to consider the directions in which remedies for it may be sought.

Air has been recognized as a cause of corrosion for many years, and instances of rapid corrosion have been proved to be due to the feed-pumps sucking air from the hot well, and to the feed being delivered at a level considerably below the water-line. The boilers that have been most free from this kind of corrosion are those in which the best means have been adopted to exclude air. But it is doubtful whether marine-engine designers have exhausted all the possible expedients in this direction.

When air is dissolved it is difficult to extract it entirely from the feed-water on its way to the boiler. It seems, therefore, that the only remedy is to prevent it from being dissolved. As the steam passes from the boiler through the engines and condenser, it has no chance of meeting with air till it arrives at the air-pumps. As at present arranged, the air-pump is a most efficient arrangement to cause water to dissolve air, and when it has left the air-pumps the water is exposed to the air in the hot well. The simplest remedy appears to be to put the hot well between the condenser and the air-pump, and to make it a separator of water and air (*Fig. 2*). The air-pump would then extract the air, and the

feed-pumps would pump the water back to the boiler. This may be accomplished in other ways, but, whatever might be the practical difficulties, no doubt marine engineers would be equal to the task of overcoming them, if once they realised the paramount importance of returning the water from the condenser to the boiler without allowing it the opportunity of dissolving air.

Fig. 2.



A remedy for all kinds of corrosion that has been much recommended is to admit sufficient sea-water to completely cover the inside of the boiler with a thin scale of sulphate of lime. The formation of such a scale is often erratic, and even if formed it is apt to be cracked and thrown off by expansion and contraction. Oxide of iron formed before the boiler is regularly steamed would be hydrated. When the boiler is filled with salt water, the sulphate of lime scale is formed in a few hours, and being a non-conductor the plate and oxide are overheated. This would cause the water of hydration to be driven from the oxide and the scale would crack off that part. Such places are more liable to be corroded because the surrounding scale deflects the current of water against them. But the great objection against a scale is that it interposes a non-conducting layer between the metal and water, and if there is also a second insulating layer of froth, the metal is most liable to be seriously overheated.

The effect of putting lime into a boiler filled with distilled water appears to be very small. If sea-water is present the lime converts the magnesium chloride into calcium chloride, and the magnesium sulphate into calcium sulphate. This takes a considerable quantity of lime, and does not appear to be worth doing.

Carbonate of soda is, however, a really useful remedy with distilled water; as may be seen it practically stops the corrosion. But carbonate of soda cannot exist in sea-water till it has converted all the magnesium and calcium salts into sodium salts, and to ensure an excess of soda it is necessary to put in 45 lbs. of

soda crystals to every ton of sea water admitted to the boiler. As it is not possible to find out what quantity of sea water is leaking in through the condenser, this treatment is not easy; the only way being to test the water and prove it to be alkaline.

Zinc slabs well connected with the boiler plates are successful in protecting the plates from the action of air corrosion. If sea water is present it acts upon the zinc, wasting it very fast. It has been thought that the zinc salts produced arrest corrosion, but this does not appear to be the case.

It will be seen from Table I that zinc chloride and oxide seem rather to increase corrosion, and zinc sulphate is as bad. As to the action of zinc in boilers, some chemists hold that it is only the hydrogen given off when the zinc chloride is formed that unites with the oxygen, and that 90 per cent. of the zinc is wasted, and others hold that its beneficial effects are due to galvanic action. It is, however, generally agreed that zinc cannot be relied upon to protect the tubes of a water-tube boiler.

It is recognised that oil should not be allowed to enter a boiler. Most marine engines are worked with very little oil admitted to the valve-chests and the cylinders, but it still seems necessary to oil the piston-rods. It would be a great boon if a gland packing could be used which would run without oil, but in the meantime all that can be done is to employ good filters, to maintain them well, and to use only pure hydro-carbon oil in any situation from which it can be carried into the feed-water. Animal and vegetable oils are chemically changed by the steam, and the products pass even the best filters and are carried into the boiler. Hydro-carbon oils are now generally demanded, but it is desirable to make sure that the oil is not mixed. A very simple test will prove this. Heat a small quantity of the oil and add sufficient of an alcoholic solution of caustic potash coloured by phenolphthalein. If the red colour stands, the oil is a pure hydrocarbon, but if it does not, the oil is unfit for use in the way referred to.

The evils due to air would cease if it could be excluded, but the evils due to froth are more persistent; the only palliative is to improve the circulation, and to limit the fire heat to enable the water to wet the heating surfaces as much as possible.

The Paper is accompanied by two tracings, from which the Figures in the text have been prepared.

Discussion.

The President. The PRESIDENT thought the members would agree with him that a hearty vote of thanks was due to the Author for his important Paper, which raised a subject of great importance both to the Navy and to the mercantile marine.

Mr. List. Mr. J. LIST said the Paper was certainly an important one. It was found in marine boilers of the water-tank type fed from surface condensers that the severe form of corrosion known as "pitting" could only be prevented by the continuous expenditure of an amount of zinc, the cost of which was a not unimportant item in working-expenses. In the application of zinc the following points required attention:—First, it should be in the form of rolled plates to ensure a crystalline structure sufficiently fine-grained to avoid breaking up of the metal by separation of the crystals in the process of oxidation which went on in the boiler. Secondly, it should be free from impurities which would tend to set up local galvanic action. Thirdly, it should be in a form which exposed a large surface for a given weight (the protective effect being in proportion to the surface). Fourthly, the surface of the zinc should bear a definite ratio to the internal wetted surface of the boiler (exclusive of the steam-space). Fifthly, the zinc surface should be uniformly distributed over the surface intended to be protected. Lastly, the zinc should be in metallic contact with the steel of the boiler. Some of these conditions could only be imperfectly fulfilled. To have maximum surface for a given weight, thin sheets would be required; but if these were used, it would be found that oxidation would quickly break up the zinc, and renewal at too frequent intervals would be necessary. In practice it was usual to fit plates ranging from $\frac{3}{4}$ inch to 1 inch in thickness. To ensure metallic contact, the studs and nuts holding the zinc should be faced and kept bright. On examining plates which had been in use, it was found that the surfaces which had been in contact with the shoulder of the stud and the nut were only partially oxidized, and the surfaces there were smooth and compact, while the whole of the exposed surface of the plate was rough, and had oxidized away in flakes, leaving a core of metallic zinc. He had tried soldering a copper wire into the zinc, and nipping the wire between lock-nuts on the stud to ensure good contact, but found that the wire became loose

in the zinc by oxide forming round the solder. Uniform distribution of the zinc over the surface of the furnaces, combustion-chambers, and shell (below the water-line) was fairly practicable; but it was not possible to distribute it over the tube-surface. Where the boiler was fed by float-controlled direct-acting steam-pumps—in which case only the air dissolved in the water was pumped into the boiler—the life of the tubes was found to be satisfactory if the zinc protection of the boiler was sufficient, even though it was not uniformly distributed over the tube-surface. In the case, however, of boilers fed by pumps worked off the air-pump levers, which frequently delivered an excess of air with the feed, the life of the tubes was considerably shortened, and an increase in the amount of zinc surface did not get over the difficulty. If the proposal of the Author to pump the feed direct from the condenser to the boiler would obviate the expenditure of zinc to which he had referred, and if the mechanical difficulties were not so great as to make the cure worse than the disease, the arrangement would, he thought, be advantageous even for tank-boilers. In water-tube boilers which could not be effectually protected by zinc there appeared to be a still wider field for its application. The difficulties to be overcome were, he thought, these:—First, the cooling-surface in the surface-condenser must be large enough to reduce the feed-water to a temperature at which there would be no difficulty in dealing with it in the feed-pump. Secondly, the water would require to enter the pump under sufficient head to lift the suction-valves, and that was a point which was by no means free from mechanical difficulty. Thirdly, to effectually pump air only without water an air-pump of special type would probably be required. Fourthly, the feed-pump would require to be of a type which would pump water freed from air without the well-known water-hammer action. Fifthly, the float-control tank would require to be under vacuum, and also the feed-filter, unless the latter was placed between the feed-pumps and the boiler, which was undesirable on account of the difficulty of the great weight and cost of a filter under pressure to contain sufficiently large surface to ensure efficient filtration. Possibly the outside-packed ram type of feed-pump would be found most suitable, with, as the Author had suggested to him, a fresh water supply to chambers round the rams outside the gland packings to avoid the risk of drawing air at the glands. The whole feeding arrangement proposed was a distinct departure from existing practice, and probably many modifications in details of points would have to be tried before success was achieved. It was Mr. List.

Mr. List. not, as a rule, practicable to experiment with boiler-feeding arrangements on board ship, and on that account he foresaw some difficulty in the scheme being readily taken up. Corrosion in boilers caused by sea-water had been referred to, and in connection with that he wished to draw attention to the constant failure of brass condenser-tubes by their becoming perforated from the action of the sea-water on small particles of impurity occurring in the brass. What these impurities were and how to avoid them were questions of considerable importance, more especially in connection with the use of water-tube boilers. He thought that where there was admixture of sea-water with the feed, and where frothing and consequent overheating of the tubes took place, corrosion due to the action of hydrochloric acid liberated on the surface of the overheated tube, as described by the Author, was likely to result, and corrosion from this cause would probably be more rapid with seamless steel tubes of high-class material than with iron tubes of the quality generally used for the fire-tubes of tank-boilers. He had found that where feed-water was heated by direct contact with exhaust steam in a separate heater having a connection to the condenser—the object of which was to free the water from dissolved air—if such water were allowed to impinge directly on the heating surface from a leaky joint in the internal feed-pipes of the boilers severe pitting took place. Also, he had found that it was not possible to prevent pitting in boilers fed with water from such heaters without the use of zinc. In the cases in question nothing but pure hydro-carbon oil was used for lubrication, and very little of that, therefore the pitting could not have been due to fatty acids from the oil. In regard to the desirability of having a gland packing which would run without oil, metallic packings for piston-rods were now largely used with success, but, so far as he knew, they were all composed of white-metal alloys, which required a certain amount of oil on the rod to keep down excessive wear. Referring to the question of water-tank *versus* water-tube boilers, he did not think there was at present in the market any boiler of the latter type with which it would be practicable to run mail steamers on long ocean voyages with anything like the freedom from breakdown or the small cost for upkeep which long experience with the former type had shown was possible. He thought that superheating offered distinct advantages from the point of view of economy of fuel, but it was, in his opinion, impossible to use superheating at sea so long as there was risk of admixture of salt-water with the feed, as with the motion of

the ship in heavy weather salt-water in small quantities would be carried up into the superheater and severe corrosion would result from the liberation of hydrochloric acid on the hot surface of the metal. He had seen it suggested that superheating might be effected by arranging coils of tube containing oil in the uptakes and connecting these to a circulating system in a closed vessel through which the steam passed, the heat carried by the oil being transmitted through the metal of another set of coils to the steam. He did not offer any opinion as to the practicability of the scheme, but it certainly appeared possible to get over in that way any question of corrosion of the tube surface. Referring to the question of corrosion in water-tube boilers when not in use, one effectual preventative was to maintain the boilers empty and open, and to keep them thoroughly dry and warm by small braziers of live coke—free from sulphur—placed in the furnaces. The whole question of the durability of water-tube boilers in Her Majesty's ships was one deserving of the best attention of engineers and chemists who had expert knowledge of the subject. Such boilers were necessary for war-ships, and their maintenance in an efficient condition was of vital importance. Mr. List.

Mr. F. H. R. Sawyer's experience with marine boilers, like that of the last speaker, had been principally confined to the tank-boiler, or ordinary modern return-tube boiler. Between the years 1882 and 1892 he had some forty steamers under his survey, and he could confirm from his experience what Mr. List had said, viz., that the only effectual means of preventing corrosion was the application of zinc. It appeared also that a contrivance which he had come across during those years was the very best method of applying the zinc that could be devised. Instead of the zinc being in plates screwed or attached to the surface of the boiler, two balls of zinc were cast upon a copper bar about 3 feet long, and those balls were hammered on the outside—presumably to solidify the metal—in order to prevent a too rapid wasting away. The arrangement was called the "electrogen," and several sets of them were placed in each boiler, two or three in a single-ended boiler, and four or six in a double-ended boiler. They rested upon hangers, which were fastened to the upper row or to the second row of tubes, about 3 feet from the tube-plates. One end of the bar was connected by a copper wire to a stud, which was screwed into the top of the combustion-chamber, while the other end was let down and fastened to a stud in the furnaces below the level of the furnace-bars. It was his experience during many years that boilers fitted with those electrogens Mr. Sawyer.

Mr. Sawyer. presented a far better surface than any not fitted with them. That was perhaps not an absolute proof of the advantage of the arrangement, but he thought it went a long way towards it. The balls of zinc certainly wasted much more slowly than the plates, which in some of the vessels were screwed to the sides of the boiler. It had been stated that it was generally agreed that zinc could not be relied upon to protect the tubes of a water-tube boiler. He hoped that some further information would be given on this point. He had had experience with the water-tube boiler of a yacht, in which the tubes were entirely pitted and destroyed in 2 years, notwithstanding the fact that there were several large slabs of zinc about the boiler. He noticed that the Author had not mentioned anything about the quality of steel in the boilers, or the nature and composition of the tubes; but his memory carried him back to the time when the first steel boiler was fitted—at least, the first he heard of, he thought—in the "John Penn," which some members might remember. He believed that the life of that boiler was counted almost by weeks. About the same time two other vessels made a voyage to Calcutta, and their boilers were taken out when they returned, being useless. He presumed that was due to the quality of the steel not being satisfactory, and that certain parts of it were more subject to corrosion than others. A tank-boiler, if carefully looked after, lasted a considerable time. During the period referred to above he had surveyed a boiler that was 12 years old. He made a No. 3 survey of the ship which contained that boiler, and, to the best of his recollection, the boiler was as good as new, and he allowed it to work at the original pressure. That was a very unusual experience, but it showed the effect of taking great care of a boiler. Nothing had been said about the practice which was frequently adopted on board ship, namely, washing the furnaces and the inside of the boiler with cement-wash. His experience did not coincide with that of Mr. List when he spoke of the corrosion of tubes being a matter of the greatest import. In all his experience the sides of the combustion-chamber, and the sides of the furnace a little below the level of the fire-bars, were the places where the worst corrosion and pitting took place. Of course tubes did require to be replaced, and it was practically easy to do that without disturbing the boiler, but the renewal of a combustion-chamber or a furnace was a very different matter.

Mr. Milton. Mr. J. T. Milton said his experience also had been mainly gathered in dealing in his professional capacity with tank-boilers, in regard to which the question of corrosion was not nearly so

serious at the present day as it used to be very many years ago. Mr. Milton.
Mr. Sawyer had spokén of a 12-year old tank-boiler as being rather wonderful. At the present day there were hundreds of boilers of double that age in use at sea in the merchant service. He did not say they were all now as good as new, yet they were 24 years old. He mentioned that fact to show that the question of corrosion was not nearly so important with tank-boilers as it was with water-tube boilers. A few months ago Sir John Durston had said, in a valuable Paper he had presented to the Institution, that the life of the tubes of a Belleville boiler might be taken as being at least two commissions, namely, six years. That was a very short time compared with the life of the tank-boiler, and the reason for it probably was, that whatever might be the corrosive influence in a boiler, that influence in a tank-boiler was mixed with a large quantity of water. When the same corrosive influence was introduced into the water-tube boiler, it was much more concentrated. There were one or two points in the Paper on which he was not quite in agreement with the Author, who had stated that iron and steel would not unite to any considerable extent with the chemically combined oxygen of water at a temperature below red heat. His experience was altogether the reverse, and he thought the Author did not prove what he said. His experiment was not conclusive, because it was made at a temperature very considerably below red heat. It would be noticed in what detail the Author had described to the members how he made his experiment, which was no doubt conducted with great care. The highest temperature he obtained was that of steam at a pressure of 300 lbs. per square inch, which was a long way below red heat. He further added "it must, however, be borne in mind that the tube was not under the same conditions as the heating surfaces of a boiler, as there was no chance of over-heating." Again, the Author said that where there was no scale, it was possible to overheat the metal of the boiler. Some experiments had been made by Mr. Yarrow some time ago in which he very severely forced some water-tubes in a boiler. They were perfectly clean and he could find no extra expansion of metal during the forcing of the boiler, showing that when the tubes had water in contact with them the temperature of the metal could be raised very little above the temperature of the water. The experience Mr. Milton had in his mind was mainly experience of superheaters years ago. When superheaters were used with marine boilers, if they were any good as superheaters they lasted a very short time. In his experience of surveying superheaters,

Mr. Milton. whenever he had found a superheater in good condition he had invariably found that it had never been used as a superheater, but merely as a steam-chest. For some reason or another evidence of this could generally be found in the superheater itself. There was often drainage-water from the priming of the boiler, and there was a watermark in the bottom of the superheater, showing that it could never have had in it anything much hotter than saturated steam. If the superheater was really superheating the steam it corroded with remarkable rapidity, whether it was of iron or of steel. It was owing to that exceedingly rapid corrosion of superheaters, he believed, that marine engineers would not think of them at the present day. He did not think any marine superintendent would now dream of putting in a superheater with a large surface exposed to pressure, as used to be done years ago. He thought the Author's explanation of the way in which corrosion took place showed why it was that rust, allowed to remain on iron substances, corroded them very rapidly. Sesquioxide of iron seemed to be an unstable compound. When oxygen was not present in excess, the oxygen of the sesquioxide would, under certain conditions, take up more iron and be converted into a less oxidised form, which, when oxygen was present in excess, was oxidised rapidly into sesquioxide again. He believed that what used to happen in the superheaters must have been something of that kind; but whatever might have been the cause, there used to be found in them large accumulations of thick heavy rust, and that rust was always found in the hottest part of the superheater, where the surfaces were used in heating the steam. There was one point on which it was possible that members who had had experience of water-tube boilers could furnish some information, viz., as to the correctness or otherwise of the Author's view that the greatest corrosion would take place where the action of the fire on a heating surface was fiercest. In every water-tube boiler, one side of each of the tubes was exposed to much greater heat than the other, by the direct action of the fire. Perhaps some of the members might be able to say whether, when water-tubes did corrode, they corroded most rapidly on the fire side; if so, that would show there was a great deal in the question of the rapid transfer of heat. With regard to zinc in boilers, his experience, and the experience of most of the colleagues with whom he had discussed the question, was that zinc was a most useful thing to put in a boiler. Over and over again he had found it to be so, and the conclusion was now beyond all question in his mind. When he was engaged every day in surveying boilers, he found that boilers

which gave trouble without zinc, almost invariably gave much better results in the matter of corrosion when zinc was used. He thought one of the chief reasons why the tank-boiler at the present day was not seriously troubled with corrosion was that zinc was now nearly universally employed. Mr. Milton.

Mr. Weston observed that the Author had referred in his opening remarks to the chemical action which took place in corrosion. He desired to supplement those remarks by pointing to the fact that such chemical action was very considerably intensified by electrical action, such as the local electrical actions which were set up by the accumulation of the products of oxidation, especially when hardened into scale. In fact, it was rather difficult to find two surfaces of a steel plate which would not show a current through a galvanometer. He remembered many years ago making some experiments on the corrosion of steel plates, one of which was planed to remove the outer skin, and after immersion for 6 months in sea-water it was found to have large patches, covering over a third of the plate, perfectly bright and without the slightest trace of rust, showing that those patches had been in an electro-negative condition, or in a condition insensible to chemical action. Again, mechanical action considerably intensified chemical action. In a protected plate chemical action was suspended, and mechanical action had no power; but if chemical action took place, mechanical action, by clearing the surface of all products of oxidation, permitted chemical action to go on at its maximum rate. It was granted that sea-water or fresh water with which the boiler was supplied was harmless if the water was free from air. The converse was also true, that air free from moisture was harmless. If an old boiler, with a large accumulation of scale, were closed up for about 3 months and then examined, the air in it would be found to contain not a trace of oxygen; but if a tray with lime were introduced so as to absorb the moisture, the air, allowing for slight action whilst the lime was drying it, would contain more than 90 per cent. of oxygen, perfectly good, so that the boiler could be entered and the usual candle would burn easily. Again, water not free from air was innocuous, and would not attack iron if a certain quantity of lime or carbonate of soda was introduced. There were these factors in the ordinary cylindrical boiler—for he was dealing only with that at the moment; (1) the internal surface of the iron; and (2) the salt water or fresh water in the boiler. Admitting that water free from air would not attack iron, the Author, whilst proposing to remove the air from the water, did not show that there was an Mr. Weston.

Mr. Weston. alternative method. That method had been suggested by Mr. Weston 25 years ago, and was to throw the internal surface of the boiler below the water-line into an electro-negative condition, or a condition in which it was insensible to any action. That was done by setting up a battery in the boiler by using zinc plates. When proposed it was intended as a summary measure for the time being, corrosion being then a very costly item; but a large Boiler Committee, which was then sitting, failed to propose a different method, and the Admiralty had been so well satisfied with it that it had held its own for 25 years. It was necessary that the zinc should be rolled zinc; cast zinc would not do at all. Although he had no knowledge of the mercantile marine, and he did not like to refer to any modification adopted there, he had some knowledge of the electrogen which had been referred to, which had been tried in the Service. It was a cast ball of zinc hammered on the surface. Such hammering did not proceed to the centre, and the waste of zinc was comparatively small, as had been rightly said, because the action was small. Tests had been made by insulating every plate of zinc in a boiler and carrying the current through a galvanometer, with the result that a very considerable action was indicated, which, at the end of 6 months, was found to have diminished but slightly with the wasting of the zinc. In the case of the electrogen, however, similarly tested, the action soon became very slight. It all arose from the one fact that rolled zinc must be used. A cast zinc plate would be seen to have separated into its individual crystals with a black insulating medium between. The remark had been made that the cost of using zinc was considerable, and of course to make it efficacious the zinc plates had to be wisely distributed so as to bring every portion of the surface of the boiler within reasonable range of a plate. The cost of the zinc was small compared with the expense of renewing a boiler after comparatively few years; and to the cost of the boiler must be added the cost of destroying the decks of a ship in order to remove the old boiler and replace it by a new one. He would leave the Author's proposal to remove the air from the water to be dealt with by engineers; but he might mention water-hammer action as one of the difficulties that would probably have to be faced in the manipulation of water deprived of air. He thought he might safely say—and Mr. Milton largely confirmed him in that view with regard to the mercantile marine, although a little more care was used in regard to metallic connection in the Navy than time probably permitted in the mercantile marine—that there was very effectual preservation. However, as far as his experience

went, he believed that corrosion of the old cylindrical boiler had not troubled the Admiralty for the last 25 years. He might remark that the statements made in the Paper respecting zinc were a little confusing, and he scarcely understood what the Author meant by them. Zinc had been spoken of as used without metallic connection; that had been the case, but he did not know whether the practice was still continued. Many years ago, when there was quite a panic on the question of corrosion, zinc was introduced into boilers to act chemically on the copper which it was supposed the condensed water dissolved from the tubes of the surface-condenser, and carried forward into the boiler, where it was precipitated. A Mr. Trotman had introduced some boxes into the path of the feed, and made the feed-water pass through zinc cuttings so that the copper might be deposited. As a matter of fact, the amount of copper dissolved was infinitesimally small and would do no harm; but zinc used galvanically in a boiler of course protected it from action of any kind. Before passing on to water-tube boilers, he would like to confirm a remark made by the Author with reference to the effect of the use of forced draught necessitated by the increased pressure of steam. He did it simply to illustrate the fact that the use of the cylindrical boiler was not going to be free from difficulties even if it was continued; and a stage had been arrived at when the forced-draught question introduced a difficulty. The first difficulty was that the tubes began to leak, and that was overcome by the introduction of ferrules; but it was found recently that, whilst the boiler was generally protected by zinc, solid water contact on the top of the tubes near the tube plate was considerably interfered with by the rapid evolution of steam, and such interference was a powerful cause of corrosion: there was decomposition of the steam by the metal and there was considerable pitting just at that end. Mr. Weston.

Passing on to water-tube boilers, experience of them was not long enough to allow of making dogmatic assertions. More experience had been gained of small-tube than of large-tube boilers, and it was with the former he proposed to deal. The Author said it was considered that zinc could not be used to protect water-tube boilers. That was correct as regarded large tubes, but not correct with regard to the small-tube boilers, which consisted mainly of tubes totally submerged; there was water-connection between the tubes, the steam-drum at the top and the water-reservoirs at the bottom. Those boilers could be protected from ordinary corrosion with zinc, and it was used effectually, but at present it was not

Mr. Weston. available for the large-tube boilers, except for a portion of the boiler only. Therefore, there had been a little difficulty with such boilers in regard to corrosion. The small-tube boilers were of two kinds, viz., those with totally submerged tubes, and those with partially submerged tubes. In the latter there was a break in the water connection between the steam-drum and the tube on the upper side. A boiler of that type happened to be the pioneer in the Service, and the experience was that after 3 years, with the aid of zinc, the tubes under water were in very good condition; in the fourth year the boiler seemed to have been called upon for extra service, and there was a very considerable falling off in the condition. He thought it must be assumed that there was produced as the effect of the fire upon the tubes destruction of the solid water contact between the sides of the tube and the water. There had been less experience with boilers with totally submerged tubes, but so far they were in excellent condition. His belief was that those boilers would answer every call made upon them without destroying the solid water contact, because it was possible to replace more quickly water which was displaced by the steam in escaping upwards, both from the upper part as well as from the lower part. He had good reason to believe there was as yet no destruction of the solid water action, and that was important, because destruction of the solid water contact introduced a sort of corrosion which was far more powerful than any ordinary corrosion. It was necessary to face the decomposition of the steam by the iron. Reference had been made to the subject, and the Author had referred to the question of the temperature at which the decomposition took place. At the Admiralty they had gone a little more thoroughly into it, and he could say there was no decomposition of dry steam below 930° F., and no large amount of decomposition was obtained until a temperature of 1,150° F. was reached. The production of acidity by decomposition of some of the salts in sea-water, especially the magnesium salts, had been mentioned. Assuming that there was a small decomposition, it was not so serious a matter as the injury which resulted from the decomposition of dry steam by the iron itself. He was aware that decomposition did take place when magnesium chloride was evaporated down, but he thought the Author's suggestion was somewhat far-fetched. As an illustration, he might mention the case of an accident the Admiralty had had with one of their water-tube boilers. In this case there was a considerable deposit of salt, due to the unfortunate accident of the introduction of salt water. He had tested such deposits which had occurred in

practice, but they would not give any trace of acidity to litmus paper. All the engineers in the Navy were supplied with litmus paper, and there had been no complaint of acidity so far. If such a result were obtained from the small-tube boilers, it might be fairly assumed that it would be obtained with the large-tube boilers, as to which, however, he hesitated to say anything, because as yet but little experience of them had been gained. In conclusion, he would like to say that, although he had questioned some of the conclusions in the Paper, he thought the Author had certainly brought forward points in a manner admirably calculated to evoke a satisfactory discussion. Mr. Weston.

Mr. List asked whether Mr. Weston could give any information about the pitting of condenser-tubes. Mr. List.

Mr. Weston replied it was a subject quite apart from that before the Institution, but he might say that the trouble in question was not always present. It did not occur when cast-iron condensers were used; in that case the tubes were saved at the expense of the cast-iron casing. When cast-iron casing was done away with, the tubes suffered, the casing being generally slightly electro-negative to the tubes, so that a slight action was obtained the other way. Mr. Weston.

Mr. List observed his experience was that with cast-iron condensers the tubes pitted badly, and he had found the same thing with wrought-iron condensers and with galvanized-steel condensers. In all the cases to which he referred the circulating water passed through the tubes. The real point at issue was what was the foreign substance in the brass? If it was possible to find out the cause of its presence, and the way to keep it out, it would be a very important matter. Mr. List.

Mr. Weston considered Mr. List's experience did not agree with that in the Navy; there no difficulty whatever occurred with the tubes until the change was made from cast-iron casings to brass casings, because the tubes were electro-negative to the cast-iron. Now the tubes and the casing were not of the same metal, and what he had said with regard to two kinds of iron applied still more forcibly to two different metals, which could not be used without considerable action occurring between them. Condensers made of the same metal throughout—tubes, tube-plates and casings—were now being tried, and time would show the result. Mr. Weston.

Mr. Milton thought Mr. List and Mr. Weston were not referring to the same thing. He did not think Mr. Weston meant that brass condenser-tubes corroded because they were of Mr. Milton.

Mr. Milton. brass, and he thought Mr. Weston was speaking of corrosion, which, if it took place, did so nearly all over the tubes. What Mr. List referred to was this, some erratic corrosion which took place in isolated cases of tubes, small holes pitting in them as though there were something in the material of the brass which introduced some local disturbing effect.

Mr. List. Mr. LIST asked if Mr. Weston, with his well-known experience as a metallurgist, could give some explanation of that exceptional local pitting.

Mr. Weston. Mr. WESTON was afraid he could not give a satisfactory answer on that subject. He had seen cases of corrosion that were simply beyond explanation, for instance, copper and iron tubes which were perfectly good except in the places where they were perforated through as if they had been drilled. That might be stopped by the introduction of aluminium into the copper, but it was not possible to do everything even by that means.

The President. The PRESIDENT said he had allowed this irregular discussion because he thought the particular point was most interesting, not only to those who had to do with corrosion of marine boilers, but also to members who had to do with locomotive boilers. Whether it meant that the quality of the manufactured tubes was deteriorating or whether it was due to some other cause he did not know; but he could say from his own experience that serious difficulties, similar to those which had been described as occurring in marine boiler-tubes, had occurred in the tubes of many locomotive boilers. If any members were present who had had experience of water-tube boilers, the Institution would be glad to hear what they had to say, as a good deal had already been said about tank boilers.

Mr. Anstey. Mr. W. J. ANSTEY, R.N., stated that Sir John Durston took a very keen interest in the subject under discussion, and, being unable to be present that evening, had asked him to say something on the subject with reference to experience in the Navy. Mr. Anstey had enjoyed the privilege of being associated with Mr. Weston in many investigations, and also of dealing with many of the cases which had arisen in the last 4 years and seeing many of the papers relating to them; and naturally a considerable amount of experience had been gained. The first question which suggested remark was the reference of Mr. List and others to the durability of the tank boiler. There had been no trouble in the Navy with internal corrosion in tank boilers; the experiments and report of the Committee with which Mr. Weston had been intimately associated, had given all the

necessary information, and by considering the recommendations of that Committee and applying them, all difficulties had been overcome. It was not a common thing to have a boiler 20 years old working at the pressure for which it was built; but in coming to the question of modern forced-draught performance of boilers it was necessary in the Service to apply high pressures in order to get the performance required, and that introduced a new condition. The durability of boiler tubes was not found to be the same in a boiler which was forced as in one that was worked easily. It was just as difficult and expensive to have to re-tube a tank boiler as it was to have to re-tube a water-tube boiler, and no advantage was obtained from the use of a tank boiler if the tubes gave out in 6 years when forced-draught pressures were applied to them. In the Navy there had recently been several cases of tank-boilers which had been taxed, under certain circumstances, under air-pressures, in the way in which they had been intended to work, in which the tubes had wasted early in the life of the boiler. No doubt one explanation of that wasting action was the fact that the tube had considerable difficulty in getting its water, especially if it was in the body of the tube-plate where the flame came up directly from the furnace and acted on it, particularly at the tube-plate end. The result was that if the tube could not get water, it wasted away on the water side by that strange sort of action which it was so necessary to have thoroughly explained. Mr. Anstey.

With regard to the protection of the water-tube boiler, there was still a considerable advantage gained from using zinc. The contact was important; the nature of the contact especially so. A number of cases had been successfully dealt with recently by paying particular attention to the character of the contact, which required to be a contact that an ordinary mechanic could deal with and renew; and in cases where the zinc was not so fitted, there had been some difficulty. In some of the earlier water-tube boilers, zinc slabs had been attached by means of a stud, which was screwed into the shell of one of the water-pockets, or some other suitable part of the boiler, and that method was applied because it was convenient. In the early days the importance of the contact was not appreciated; the slab was placed in that way, and then the bolt was put on the top. If the recommendations of the Boiler Committee had been properly studied, this fitting would not perhaps have been everywhere applied. It was found that an ordinary stoker or mechanic, in taking out the slab, had not a fair surface to file on; and in one case it was found that he had

Mr. Anstey. actually filed the boiler shell, which was by no means desirable. The consequence was that the slabs were not in contact, and pitting took place in the ordinary way, due partly to the action of the inflowing feed-water. The contact had therefore to be somewhat altered, an angle plate being brightened and embedded and then firmly riveted to the boiler-shell by two rivets. This connection being made once for all, the stoker or mechanic in renewing his zinc slab, had a fair flat surface, which he filed with a rough file and with which he made a good solid contact. It was found in a great number of cases in the small-tube boilers, that the application of that contact effectually stopped a good deal of the corrosion.

Several new considerations had arisen in connection with the corrosion of water-tube boilers, and one of them was that the water-space was limited. Reference had been made by Mr. Milton to the fact that what was introduced into the water-tube boiler in the nature of a corrosive substance, air or dissolved gases, had a very limited space to act upon, and therefore its action was intensified. Mr. Anstey had found many cases of corrosion which were attributable to that cause, the corrosion having taken place close to the entry of the feed-water. It was arrested very largely by the application of zinc. Again, there was a very rapid passage of the steam and water over the heating surfaces, and there was a theory of corrosion, which was well worth studying, which had been advanced by Mr. James Weir of Glasgow, and might be familiar to many members of the Institution. In a Paper[1] read before the Engineering Congress at Chicago in 1893, Mr. Weir had dealt with the subject, and had described some very interesting experiments which he had carried out. His theory was, that the oxide which was first formed by the action of the air was dissolved and carried off in some way by the gases which followed afterwards, or by some other substances in the water; and he was able to demonstrate, by the introduction of carbonic-acid gas, that after a stream of water free from that gas had passed over the surface of the experimental plate and corroded it, then the carbonic-acid gas changed the oxide and made the plate ready for further attack by the air or the oxygen which was corroding it. Mr. Weir's name for it was the "oxygen pick and carbonic-acid shovel" theory. It might be that some of the trouble which had been found with the tubes of water-tube boilers was due to some such action as this, and that the

[1] Proceedings of the International Engineering Congress, Division of Marine and Naval Engineering and Naval Architecture. Vol. II. Paper No. xxx.

rapid flow of water and steam over the surface had an important effect. A new feature, to which Mr. Weston and others had referred, was that the surfaces were subjected to steam on the one side and fire on the other. No one had yet succeeded in materially diminishing such corrosion as took place under those circumstances, and it probably would be necessary to avoid such surfaces as much as possible in a boiler. Mr. Anstey.

There were water-tube boilers now in use in the Navy, having the original tubes with which they were fitted 6 years ago. At the end of 1894 the Admiralty began very largely to use water-tube boilers of the small type in destroyers, and there were a number of destroyers running in which the original tubes were still good. They had been carefully watched and the little defects had been detected; and by comparing those boilers which had been, and continued to be, satisfactory with some which had failed, a considerable amount of information had been obtained. One ship, which had to be despatched in a hurry, was obliged to go across the Bay, and when she was half-way across she had salt-water coming in during bad weather, and the result was that the introduction of that small quantity of salt water, which necessarily found its way into the boiler, reduced the life of her tubes to 2 years; while a sister vessel, doing much more work, was still running after 6 years with the tubes good. There had also been many cases in which the action of the fire on the tube had been very clearly indicated. One was the common case of a tube which burst—perhaps burst was not quite the name for it. It had a small elongated hole, and a slight increase in diameter. The engineer reported that the tube was drawn unequally, and had failed for that reason; but further investigation was made by cutting up the three rows of tubes nearest to the fire, first of all carefully marking them, so that the fire side should be known after the tube was taken out; and the result arrived at was that, if the engineer's explanation were correct, the tubes must not only have been drawn unequally, they must also have been carefully placed with the thin side of each next to the fire! Further, the tubes in the centre of the furnace were thinnest; in other words, those near the back and the front, where there was not so much flame-action, were distinctly thicker than the others; and the farther the rows were from the fire, the more uniform was the thickness of the tubes, until at about three rows from the fire they were of uniform thickness. It was evident, therefore, that the failure was really due to the boiler not having been fairly treated. It had had a small amount of salt water introduced with

Mr. Anstey. the feed, and the lower pockets had not been kept thoroughly clean: the consequence was that a very slight amount of sediment and slush in the boiler had entered the tubes next to the fire, and diminished the circulation to such an extent that the tubes became over-heated. One fact which had to be kept in mind was, that there appeared to be a certain ratio of length of tube, area of section, and circulating-force. The circulating-force was not a measurable quantity in practice, but there was a definite relation between these three quantities which could not be departed from without getting such a state of things inside the tube that the steam would commence to corrode the tube in some way. It was not a question of the temperature at which distilled water would act on iron; that was a laboratory experiment. The point which it was desirable to solve was, at what temperature did the ordinary water that the engineer was likely to have to use act on tubes. Considerable success had been achieved in keeping the water pure. The engineers in many of the torpedo-boats and other large ships had shown attention and ability in this direction, and had run on month after month, if their condensing tubes were tight and they had not had any special troubles in that way, without any density in the boilers. In that way their tubes had been very effectually preserved; but at some time or other there would be an introduction of some corrosive substance, and of a slight amount of sea-water, and then the question was, at what temperature was steel likely to be reasonably safe against the action which went on? He was inclined to think that the temperature was considerably lower than what was indicated by the results obtained with distilled water. He had seen a great many tubes which were partly above the water-line and which were acted on by the gases outside. Many boilers had such tubes, and it would be found invariably that the upper tubes were attacked by a sort of corrosion which could only be arrested by diminishing the extent of the flame-play upon them. It appeared from the endeavours made to reconcile the "frothing" theory with what was seen in the actual examination of a boiler, that there was no inconsistency in it, and it did not strike him as an impossible, or even an improbable, theory. But there was one thing it did not quite explain, on which the Author might perhaps be able to throw some light, viz., the fact that the oxide formed in this way was almost always magnetic. That was particularly the case where the steam was on one side, and where there was little or no water in the tube. There was one other point which experience showed to be essential in regard to water-tube boilers, viz., the

tube must be one which could be searched. Boilers were working more or less effectively with a tube through which a solid instrument, in the nature of a brush, could not be passed to clear the tube; those boilers would go on for a considerable time, and in the hands of the inventor or the patentee they might have considerable life; but directly they were put to the rough-and-tumble work of service there must come a time when, in order to ensure that the boiler should not fail when lit up, a solid searcher must be passed through every tube from one end to the other. If that could not be done the boiler was, to that extent, an unreliable one, for foreign matter would sometimes collect. In that respect, the large-tube boiler had a distinct advantage in the matter of corrosion; most large-tube boilers readily lent themselves to inspection of the tubes. To sum up his experience, he believed that in order to prevent corrosion, sea-water as well as air must be kept out, and zinc, or lime, or some other substance must be introduced into the boiler, which would deal with sea-water and other causes of corrosion when they occurred unexpectedly, as they would do in the life of a boiler in practice; and the measures adopted for this purpose must be such as could be applied by the ordinary engineer on service. He thought those present would feel that the subject of corrosion was a vital one, and its introduction by the Author most opportune. It might be within the memory of some of the members that in a discussion on water-tube boilers at the Institution of Naval Architects, two or three years ago, Mr. Scott, of Greenock, had referred to the fact that many years ago several of those boilers had been built and sent out to India, where they had been put into river-boats, but they had all failed by corrosion. It was a recognised fact that the question of corrosion was a difficulty in water-tube boilers; but it was not so great a difficulty as it was a few years ago. Those who were in closest touch with the necessities of the Navy—he could speak perhaps solely for that department—knew that the water-tube boiler was a necessity and therefore knew that the problem of corrosion must be solved. They also knew that there was more than a probability of its being so solved that it would not be in any sense considered a drawback to the employment of the water-tube boiler. At present, however, the solution of the difficulty appeared to be confined to rather too limited a circle. He had been desired by Sir John Durston to say that he and all who had to deal with the subject were much indebted to the Author for bringing it forward, and to express the hope that the discussion on it might result in bringing to the assistance of

Mr. Anstey.

Mr. Anstey. all who were interested in the solution of the problem, the general engineering ability of the country.

Mr. Robinson. Mr. MARK ROBINSON said this important and suggestive Paper had led to a question on the part of one of the speakers as to where the corrosion took place in the tubes of a water-tube boiler. Was it at the bottom, which the speaker assumed to be the most heated, or was it at the top? Mr. Robinson had had very few opportunities of looking into cases of corrosion, and he was sorry to say that when he had an opportunity he neglected to observe whether the corrosion was at the top or at the bottom. But it might be worth while to remark that apparently not the bottom but the top of the tube was the hottest. It was a familiar observation that when tubes in a water-tube boiler bent from over-heating, they arched; that was, they rose upwards, and lengthened along the top, which suggested that the top became hottest. That led to some experiments being made with glass tubes, and what was expected was observed, viz., that the steam formed in the tube rushed in huge bubbles, inches in length, along the top of the tube, denuding it of water; and thus the top of the tube, although protected from the flame, was really in a position to become hotter than the bottom. The external action of the heat was greatest at the bottom, and therefore the bottom wasted away; but so far as internal heating went it was not the bottom that grew hottest but the top, as far as he had observed. The Author's arrangement of air-pump and hot-well seemed to be very promising, but he would like to ask for some information as to what was the real probability of keeping the air out of the water by that arrangement. If no air was to get into the engine, if glands were never to leak and air were not to get in through them, all would be right; but assuming the ordinary causes of leakage and introduction of air into the condenser, he was afraid that such air as was there would be taken up by the water. The water formed by condensing the steam would fall in drops amongst the tubes inside the condenser. The condenser was filled with a mixture of vapour and air—very attenuated air, but still air; and, as was well known, water had a great faculty for picking up air, and it was extremely difficult to get it out of the water again. In an ordinary air-pump the water was exposed to alternations of pressure; first it was exposed to atmospheric pressure and then it was under a vacuum. Each time the pressure fell, the tiny bubbles of air increased in size and thus tended to disengage themselves quickly, and he believed that was how the air was got out of the water in an air-pump. Some years ago his firm put up in a Lancashire mill,

Mr. Robinson.

where there was a Willans engine of about 500 HP., a "barometric" condenser. The condenser was perched on the top of a stand-pipe about 35 feet high which discharged into the lodge, of course under water. The water was pumped up and fell in a jet through the condenser. An air-pump was installed, drawing out of the top of the condenser, and that plan worked very satisfactorily for some two or three years, until one day the pump broke down, and everybody was surprised to find that there was as good a vacuum without the air-pump as with it. The air-pump was therefore taken away. The explanation was that as the jet fell through the condenser the air was entrained in the water and carried down with it. That led to some experiments, which it might be interesting to quote, being carried out by his colleague, Capt. Sankey.[1] Air was introduced by a small pump into the lower

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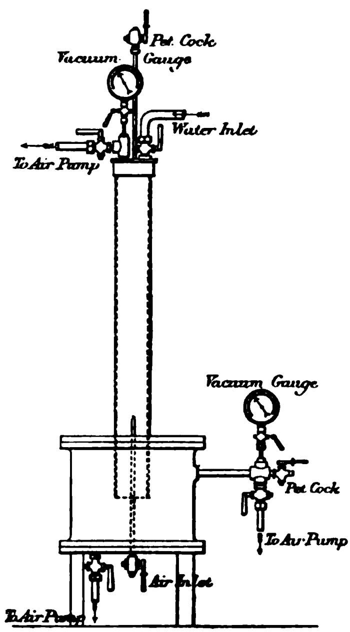
[1] Mr. Robinson has since furnished the following account of these experiments.—Sec. Inst. C.E.:—

The apparatus is shown in the diagram annexed. By means of the connection shown to the air-pump and the pet-cocks, it was possible to maintain any desired vacuum in the apparatus, and to keep a column of water in the glass tube of any desired height up to 2 feet 6 inches, above which point the water surface was hidden by the brass cap at the top of the tube. The results of the experiments were as follows:—



(1.) The velocity of the air bubbles was independent of the pressure.

(2.) The velocity varied with the size of the bubble, as might be expected, but for bubbles over $\frac{1}{8}$ inch in diameter the increase in velocity was exceedingly small, in fact, hardly measurable with the means at disposal; the maximum velocity observed was approximately 1 foot per second. Below $\frac{1}{8}$ inch in diameter the velocity diminished rapidly with the size of the bubble; and for bubbles of about $\frac{1}{100}$ inch in diameter the velocity was 1 foot in 20 seconds. With a very good vacuum—26 inches and over—microscopic bubbles appeared in the water, which had no measurable upward velocity, and floated about like clouds. A very curious effect was noticed with reference to these microscopic bubbles. They only made their appearance when the vacuum exceeded $25\frac{1}{2}$ inches or 26 inches, and at this point the transparent water became gradually milky

Mr. Robinson. part of a vertical glass tube containing water, means being provided for regulating the size of the bubbles introduced, as well as for altering the pressure upon the water in the tube. The speed at which the bubbles ascended through the water was noted, and the result was surprising. Even when of considerable size the bubbles rose at no higher rate than one foot per second. It could not be doubted that, unless there was a great fall of pressure to cause the bubbles to enlarge and rise faster to the surface, it was extremely difficult to get them out of the water; to overcome its viscosity in fact. His only fear was that such air as found its way into the engine, though no doubt limited in quantity, would be entrained in the water, and would thus remain in the reservoir and pass thence to the feed-pump, and not really be taken away by the air-pump.

Mr. May. Mr. WALTER MAY had listened with the greatest interest to the Paper, and having had experience with water-tube boilers, he thought it might be of some use if he made a few remarks upon the subject. He was appointed to one of Her Majesty's ships in which water-tube boilers were fitted to take the place of locomotive boilers which had hopelessly broken down. That ship went through a great many experiments for about two years—between 1894, when the boilers were made, and 1896. In 1896 he joined her, and she was then detailed for Fisheries Protection duty, which, he might say, was one of the most arduous duties possible. It meant being at sea day and night in every sort of weather, anywhere from the North Sea to the Scillies, and it gave very good opportunities for watching the working of water-tube boilers. He very soon found that he could take almost any liberties he liked with those boilers in the way of blowing the water overboard and filling them again with cold fresh water without doing any damage whatever to the tubes in the way of making them leak. The condensers were old and leaked, and that was why he had to do that. It taught him how

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and opaque as the vacuum improved beyond 25½ inches. By opening one of the pet-cocks suddenly, and thus spoiling the vacuum, these microscopic bubbles instantly disappeared, and the water became transparent again. A curious effect was also noticed with the very large bubbles, say about 1 inch in diameter. As they rose they appeared to roll themselves inside out, and had an appearance not unlike that of a jelly-fish. Applying these experiments to the case of a "water barometer" condensing apparatus, it is evident that a velocity in the down-pipe of 1 foot per second will just prevent the larger bubbles from rising; and that if a velocity of 2 feet per second is maintained, even the largest bubbles will be swept out of the discharge pipe at the rate of 1 foot per second.

to get every drop of water out of the boilers when the ship was in harbour; and he contended that pitting started when ships were in harbour. He did not quite agree with the Author that it originated where there was furnace-scale; he thought it started where "sweating action" had been going on. He had noticed such action in many forms of boilers, not only in water-tube boilers. In one ship he was in, about 10 years ago, the chief engineer used to examine the boilers for sweating, and wherever he saw little red marks of rust he would have them emery-clothed down and the spots burnished, and then cover the place with either thin varnish or kerosene. If that was neglected, the next time sweating took place it would be found invariably that the beads of perspiration fixed themselves on those little red spots again. If that was imagined going on inside the tube, where it could not be got at, every time ships laid up in harbour, and the tubes were not perfectly dry, it would be seen that very soon holes might be drilled in them. Such, at least, had been his experience, and he had come to the conclusion that the only way to get rid of that sweating action was to evaporate every particle of water out of the tubes of the boiler. Of course a water-tube boiler lent itself to sweating more than a Scotch boiler, as there were pockets that collected water, and the water went through the tubes instead of outside them. His mode of procedure was as follows:—When the ship came into harbour he drew the fires and blew the boilers out overboard. There was then sufficient heat left in the boiler to drive every particle of moisture out of the boiler when the safety-valves were raised. He closed the safety-valves while the hot air was still going out, and the boiler was perfectly dry. These tubes were still in that ship and though they would have to be replaced before long yet they would have lasted beyond the six-year limit laid down by Sir John Durston. With regard to the frothing in the tubes, or what the Author had described as frothing, there was no doubt that that was exactly what did take place, and that it very materially assisted the corrosion; in fact, it made it proceed with very rapid strides after it was started by the sweating action. The frothing was nothing more nor less than bad circulation, and he presumed it was quite possible to devise a means by which the circulation could be improved, so that there would be wet tubes; and if wet tubes were secured and the tubes had not been pitted to start with, then an improvement was bound to take place. He contended that pitting started in boilers the day after they were hydraulically tested, and went on until it had taken a very considerable hold Mr. May.

Mr. May. long before the boilers were delivered over to the Admiralty. The squadrons of the Navy had been largely increased and put in more time at sea; but the Navy was very much bigger, and therefore there was a much larger number of ships in harbour now than formerly. The tubes in all those ships were gradually sweating away because they were not properly dried. If the sweating could be stopped and improved circulation obtained, he did not think it was at all improbable that not only would a boiler last 12 years, as mentioned by a previous speaker, but one might be obtained in which the original tubes would last many years longer than that; and, further, the water-tube boiler would be a more efficient and economical boiler than had ever been obtained before, and a boiler which he could state from experience was far better suited to the exigencies of the Service than any other type of boiler yet invented.

Mr. Robertson. Mr. LESLIE ROBERTSON observed the Author had made in the Paper a statement which was not quite borne out by the results obtained by the nation which had had the longest experience with water-tube boilers, viz., that putting lime into a boiler was practically useless. He would like the Author to state on what data he had arrived at that conclusion, and whether it was merely on the experiments made in an open vessel with air being blown into it, or whether it was from experience gained from lengthy experiments with the Belleville boiler. In these boilers it certainly was formerly the practice to employ lime very largely. He would also like to ask the Author on what ground he arrived at his conclusion that zinc was practically no good, because it was somewhat contrary to general opinion, and it was always useful to know how those things were arrived at. Further, what proportion of zinc to the heating surface or to the volume of water in the boiler would he advise? Also, could the Author state some way of stopping the corrosion, alluded to by the last speaker, which took place when ships were out of commission, and which was really a most vital matter? There were two ways of doing it, as far as he knew—one was filling up the boiler completely with pure fresh water, and the second was drying out the boiler and closing it down. He would like to know whether the Author, or anyone, could give the results in practice attained with those two methods, and state which of the two was the better.

Mr. Pendred. Mr. L. ST. L. PENDRED said that, as bearing on the question of the effect of temperature on the rate of corrosion, he had pleasure in bringing before the meeting sections of two tubes which Mr. D. Drummond, M. Inst. C.E., had kindly lent him. They were

tubes of $2\frac{3}{4}$ inches diameter which passed from side to side in the fire-box of a locomotive immediately above the fire, and were exposed to a very high temperature. If the members would examine those tubes, he thought they would find that the amount of corrosion was very slight; and if some of the experts would look at them they would be able to say whether the eccentricity of the tubes was due to irregular drawing or whether any corrosion had taken place. The amount of deposit in the tube would also be noticed—a very thin scale arising from carbonate of lime—much less than would be expected, as the tubes had been running over 60,000 miles, and the only softening used by Mr. Drummond was 1 lb. of soda per day, placed in the tender, which held 4,000 gallons of water. It seemed rather remarkable that so small an amount of soda should affect the water, which was London water, or such water as could be picked up on the lines over which the locomotive ran. Mr. Pendred.

Mr. J. H. ROSENTHAL considered the Paper to be of national importance, because to some extent, undoubtedly, corrosion must take place in the boilers of warships; and it was of general importance, because there were to-day very few superintendent engineers or gentlemen having control of large steamship lines who would not recognize the merits of the water-tube system if they were not afraid of introducing it; and what they most feared was corrosion. The experience he had had with water-tube boilers at sea went certainly in the direction of proving that the Author's contentions as to the causes of corrosion were perfectly correct. The causes of corrosion which affected the water-tube boiler affected the Scotch boiler or tank boiler in exactly the same way, only it took longer to find out the trouble. It was true that it was difficult to keep sea-water and air out of boilers, but he could relate many instances in which ships' boilers and engines of exactly the same construction showed different results. In some cases there was no corrosion at all, and in others there was corrosion, which could only be due, not to any peculiarity of the boilers or of the engines, but to the care that was given to the maintenance of the installation. The chief element in the whole matter was the human element. It depended entirely on the superintendent or on the chief engineer of a ship whether the boilers suffered through corrosion or whether they did not. It was merely a matter of care to keep the sea-water out, and if it did get in, to test the boiler-water regularly to find out whether the boilers wanted blowing out and filling up again, whether the evaporator gave enough water, or whether sea-water had been used instead of water from the evapor- Mr. Rosenthal.

Mr. Rosenthal. ator. If the endeavour of those who had charge of ships went in the direction of teaching the engineers the advantage of keeping out sea-water and air, it would go a long way towards removing the only obstacle that many superintendent engineers found to introducing the water-tube boiler into the mercantile marine, viz., their fear of corrosion. Undoubtedly a great deal of the trouble in a boiler which suffered from corrosion, after being in use for a year or two, might be prevented from the start. If a boiler were carefully cleaned inside before it was put to work, and if it were limewashed, corrosion would take place much less easily. Again, if a boiler was filled up with fresh water to start with, particularly water containing carbonate or sulphate of lime, corrosion would be a good deal longer in starting. He thought that to a large extent lime was useful. As far as the action of zinc was concerned, it was, in his experience, very local. He had certainly seen boilers come into port having their zinc entirely destroyed; and something must have destroyed the zinc. This proved that it had some effect. Again, he thought the trouble with air could be largely minimized by feeding the boiler through the steam-space. The modification of the condenser proposed by the Author would, he thought, largely tend to overcome the trouble with air. There might always be a certain amount of air, but not any such large quantity as to cause serious trouble with the boilers. He had furnished the Author with a tube taken from a sea-going ship fitted with a Babcock and Wilcox water-tube boiler about 8 years ago. There had never been any corrosion at all in that boiler, a circumstance which was not due to any cause but the engineer's care in preventing it. He could mention other instances where in a couple of years there had been serious corrosion, which could only be due to negligence in allowing salt water or air to get in. Even in some instances in which practically no oil had been used, or where there had never been any doubt of the character of the oil that had been used, corrosion had taken place, and it could only be due to sea-water and air. He would be very glad if, in the course of the discussion, effectual remedies other than human vigilance were proposed, for they would certainly be a boon to everyone connected with an industry which was now becoming of very great importance indeed.

Mr. Halpin. Mr. Druitt Halpin remarked that Mr. Robinson had referred to a barometric condenser, and had mentioned that after the air-pump broke down as good a vacuum was obtained as before. All he could say was that the air-pump must have been very bad indeed, because the fact had to be borne in mind that at the

present moment there were engines aggregating some hundreds of thousands of horse-power on the Continent working in that way and they were being put up on a very large scale; and as exceptionally good results were being obtained from them, he could only think there was something wrong with the air-pump or in its arrangement. With regard to the Paper itself, the Author mentioned that under the circumstances he had described, the water could not be touching or completely wetting the steel, and that if the phenomenon of rapid boiling were observed closely, it would be seen that next to the steel surface there was froth and not water. He quite believed that was the fact, and it was well known that the transmission of heat to froth and to solid water were very different things. It was practically impossible to get any appreciable quantity of heat through froth, and solid water was obviously very much better. In concluding the Paper the Author had said that the evils due to air would cease if it were excluded, but evils due to froth were more persistent, and the only palliative was to improve the circulation and to limit the fire-heat to enable the water to wet the heating surfaces as much as possible. He did not know that he altogether agreed with the Author in limiting the fire-heat; he was rather of opinion that the best way was to improve the circulation and to let the boiler only do its legitimate duty of evaporation, instead of trying to make it do two things imperfectly, viz., heat the water and then evaporate it, and in that way to keep the circulation perfectly undisturbed. Two or three months ago he had shown on the screen what was going on inside a boiler when it was merely evaporating, fed in the ordinary way, and also when it was evaporating fed with water of the same temperature as the water inside the boiler, and if any member cared to see it he would show it again after the meeting. Mr. Halpin.

Mr. MARK ROBINSON asked to be permitted to offer a short explanation with reference to Mr. Halpin's remarks. Mr. Robinson's statement was intended to show that the so-called barometric condenser worked exceedingly well. Before the alteration was made there was a very good vacuum; so there was afterwards; both arrangements worked admirably, and the only thing that was wrong with the air-pump was its being there at all, because a perfectly good vacuum could be obtained without it. Mr. Robinson.

Mr. BERTRAM BLOUNT wished to comment on a point that had not been touched upon, namely, the influence exercised by the nature of the material of which the boiler was constructed on its behaviour towards corrosive agencies. The members were all agreed, he thought, that it would be desirable to exclude anything Mr. Blount.

Mr. Blount. which could cause the corrosion of tubes, whatever they might be made of, and, no doubt, if perfectly clean and pure distilled water could be obtained, and air excluded, and such ideal conditions fulfilled, an admirable state of things would be brought about. But, unfortunately, in practical affairs the ideal was rarely reached, and, instead of having pure distilled water and a total absence of air, in actual practice the water in marine boilers was more or less contaminated with salt, and contained a good deal of air; and there was overheating of some parts of the tubes due to purely physical causes, which had been described vividly that evening. On the whole, the materials of the tubes were subjected to what he might almost term unfair conditions—not quite unfair, because they had to be met—but at all events conditions that were severe. When the tubes of a boiler which had lasted very well were examined and compared with tubes from a similar boiler which had lasted very badly, the conditions being substantially the same, one was forced to the conclusion that the difference in behaviour must be due to an essential difference in the nature of the material of which the tubes were made. That had been borne out by observations he had had an opportunity of making, which were based on the microscopical examination of the metal of boiler tubes. He had observed that whereas the metal of the tubes which had stood well and were in no way pitted, was close in texture microscopically, and free from all slag or air-bubbles, the metal of tubes which had failed, and especially failed by pitting, had been faulty in those respects. It had shown some indication of cavities, of little striæ due to the enclosed gas-bubbles which had been drawn out in the making of the tubes, possibly to little particles of slag, to the irregular disposition of the proximate constituents of the metal (ferrite, perlite, and other substances now recognised as the necessary constituents of mild steel). These irregularities had their effect in inducing the formation on the surface of the tubes of such local pittings as might afterwards be increased by the causes which had been described. It seemed to him a practical conclusion that the boiler-maker should be careful to make sure that the quality of the metal was correct, not merely in chemical composition but also in microscopical structure.

Sir Benjamin Baker. Sir BENJAMIN BAKER said he had been listening for some member to make the observations which Mr. Blount had made. Engineers knew that it was not merely water-tube boilers which gave a great deal of trouble with oxidation, for in their experience differences were found which could not be accounted for on any

Sir Benjamin Baker.

ground, so far as he could see, except that which Mr. Blount had referred to, and which was evidenced by careful photo-micrographical examination of the steel. He thought it was extremely important that the study of suitable material for water-tube boilers should be carried out on those lines, and he did not think it had been done up to the present.

The Author

The AUTHOR, in reply, thanked the members of the Institution for the cordial vote of thanks which they had been kind enough to pass, and for the extremely kind manner in which the Paper had been received. His object had been to place the matter before the Institution in its simplest form, and in doing so he hoped he had not omitted any experiments and confirmations of his points which were necessary. In fact, he thought very little had been said so far which raised an issue to the conclusions at which he had arrived, and, if his remarks could in any way induce engineers to endeavour to get over the difficulties under discussion, he would be very well pleased with the result of his labours. The first point he brought forward was that air should be excluded from the boiler. It had been said that in the tank boiler the difficulties of air-corrosion were entirely overcome by the use of zinc. That was a point which he did not intend to minimise in his Paper; nor did he intend to throw any doubt upon the efficacy of zinc, as had once or twice been suggested. All he wished to bring forward was that it was agreed by most authorities on the subject that the protective action of a plate of zinc was limited to a certain distance from the point at which it was attached to the boiler. For that very reason zinc could not protect the insides of the tubes of a water-tube boiler, because they were beyond the range of its protection. The real fact was that zinc was a partial remedy for an evil, namely, the introduction of air, for which he wished to provide a more drastic and complete remedy. It seemed at the present time to be almost a universal practice that the feed-water entered the boiler with more or less air mixed with or dissolved in it, and what he wished to convey was that that air, however it got in, was an evil, and ought not to be pumped into the boiler at all; and that whether zinc, or anything else, was used to prevent air from corroding the boiler when it got inside, it was far better, if possible, to keep the air out altogether. The remedy which he had suggested, of pumping the water straight from the condenser, seemed to him to be more in the direction of a preventive, while the zinc was only a cure. The condenser was a very efficient arrangement for separating air from water. It was quite true

The Author. that whatever air was in the condenser would be dissolved in the water; but there was less air in the condenser than in most places, and therefore there was less chance of water dissolving air. It was not altogether the air actually dissolved in the water to which the water in the condenser would be limited, but it was the air that was mixed with the water which was the chief cause of trouble. The best practice was to have the arrangement referred to by Mr. List, viz., an automatic feed-pump which pumped only water, and stopped when there was no water to be pumped; and the worst practice was to have two feed-pumps, one in case the other failed, each of which was sufficient to pump all the water that was condensed, and to keep both of them at work, each pumping half a barrel of water, the other half being filled with air. The hot well was emptied, and the half barrel of air was pumped in with the water. After that had been done many engineers provided means for getting some of that air away, but the small bubbles of air mixed with the water were not very easily separated. He thought that if the water were pumped from the condenser straight back into the boiler there would then be only a small quantity of air dissolved in it, because the quantity dissolved was proportional to the pressure; and the difficulty would be to a large extent avoided. With regard to the introduction of salt-water into boilers, the accompanying Table showed the variation

—	Chlorine in Grains per Gallon.	
	Boiler-Water.	Sea-Water.
Royal Albert Dock . .	160	160
Gravesend	1,081	924
Biscay	2,150	1,379
Cape Finisterre . . .	3,255	1,429
Gibraltar	4,000	1,441
Malta	4,250	1,466
Alexandria	4,448	1,466

in the constitution of the water in the boilers of a passenger steamer fitted with condensers, and, as far as one could tell, with every modern convenience. Samples of water taken at different stages of a voyage from the Thames to Alexandria showed that, whereas it began with the water fairly pure at the docks, the proportion of salt in it by the time the vessel reached Alexandria was about three times as great as the proportion of salt in ordinary sea-water. That was a state of things which he had found in his own experience to exist on a very large number of ships which were

The Author. presumed to work with fresh water, and it was a state of things which ought to be prevented. There were many causes for salt water getting into the boiler, and one of them had been spoken of by Mr. List in that part of the discussion which the President had referred to as irregular. He had been asked by two members to say a few words on the subject of brass, and it was not altogether beyond the scope of the discussion, seeing that salt water had such a large effect upon corrosion. He had had extensive experience of brass tubes, and the deterioration that had occurred of late years in brass seemed to him to be largely due to the fact that the copper which was supplied to Birmingham at the present time was considerably more arsenical than it used to be years ago. There was a very great deal of arsenical copper now in the market, and copper refiners knew that arsenic prevented copper from alloying with zinc in the homogeneous way pure copper would alloy. All refined "best select" copper was tested by alloying it with zinc to ascertain whether the arsenic and other impurities had been sufficiently eliminated. Perfectly pure copper could be alloyed with zinc in the proportion of 2 to 1, and a very homogeneous brass would be obtained. But a certain proportion of arsenic in the copper would produce a very crystalline structure, and containing crystals of two alloys, one richer in copper and another, separating afterwards, much richer in zinc. The alloy containing most zinc was dissolved at first by sea-water, and any oleic acid present in the lubricating oil also facilitated the corrosion of the zinc. It was known from the experience which had been obtained of zinc in boilers, that it was one of the most chemically active metals, and considering that there was great danger of its not being homogeneously alloyed with the copper, it seemed to him the best thing to do was to harden the copper with some other metal, which would be less chemically active than zinc. Such a result could be obtained by hardening the copper with 5 per cent. of tin. The alloy thus produced had all the ductility required for a condenser tube, and was very homogeneous. If copper containing 5 per cent. of tin was used instead of brass for condenser tubes, he thought the tubes would stand the corrosive action of sea-water much better than brass tubes; and that might be the remedy for the trouble caused by the perforation of the tubes, and hence the means of keeping out a great deal of the salt water from the boiler. The theory he had put forward of the corrosion of tubes on the heating surface by hydrochloric acid generated on the spot, so to speak, had been confirmed by Mr. Anstey, by pointing out that in one case of a water-

The Author. tube boiler each tube was found to be thin on the fire side. The point to which he would like to make further reference was that, under suitable conditions, the magnesium chloride in sea-water gave off the whole of its chlorine as hydrochloric acid when it became heated on a hot surface, that was, when the water had been evaporated into steam. As long as there was magnesium chloride left in the water there must be hydrochloric acid if any steam was evaporating at all on the heating surface. The reason why it did not always corrode the boiler was that if sea-water was continuously and slowly coming in, sulphate of lime was deposited with the salt, and that sulphate-of-lime scale, the egg-shell scale, was deposited on the heating surface, and protected it. The erratic way in which the sulphate of lime was deposited was the cause of the extreme uncertainty which existed in the corrosion of boilers. Some boilers would corrode and some would not, the reason being that the boilers which were taking in their sea-water all the time would be protected, whereas boilers which took their sea-water in intermittently from various causes were liable to be corroded. He had been also asked why the oxide formed in this way was almost always magnetic. When the magnesium chloride was left behind upon the heating surface the heat caused it to unite with the last of the water, forming magnesia and hydrochloric acid—

$$MgCl_2 + H_2O = MgO + 2\,HCl.$$

The magnesia dissolved in the boiler water and the hydrochloric acid attacked the iron of the plate if it was not covered with a sulphate-of-lime scale, producing ferrous chloride and hydrogen—

$$2\,HCl + Fe = FeCl_2 + H_2.$$

The ferrous chloride united with the magnesia previously dissolved in the boiler water, forming again magnesium chloride and ferrous oxide—

$$FeCl_2 + MgO = MgCl_2 + FeO.$$

If there was a considerable excess of air, this ferrous chloride would be oxidized into ferric oxide rust, but if the quantity of air in the water did not happen to be sufficient for that, it would be found as magnetic oxide as observed by Mr. Anstey. The very interesting question of the nature of the steel, which, of course, had a great deal to do with the rate of corrosion, had been raised. If a perfectly homogeneous steel could be obtained it ought to withstand the corrosive action better than steel which was full of faults, or was very crystalline. But that theory was not alto-

gether confirmed in practice, because it was often said, and he believed the statement was borne out by experience, that wrought iron, which was less homogeneous than steel, stood better than the latter; so that if it was really the homogeneous material that stood the better, steel ought to be better than wrought iron; but as wrought iron did stand better than steel in most cases it rather complicated the matter. However, the nature of the steel used for making boilers was a subject to which much careful study had been devoted, and he thought a large amount of attention had been given to that particular point, with a view to get as homogeneous a steel as possible. There were so many other conditions which had to be considered that he thought the steel-makers had done all they could to secure a homogeneous product. What engineers had to do was not to place much reliance on the results of efforts in that direction, but to make the strongest possible effort to keep air and sea-water out of their boilers. If that aim could be realised, boilers —whether water-tube boilers or tank boilers—would last more than the 24 years mentioned by Mr. Milton. The Author.

Correspondence.

Commodore B. F. ISHERWOOD, of the United States Navy, remarked, in reference to the Author's statement that corrosion in marine boilers was principally due to the chemical union of the iron of the plates and tubes with oxygen dissolved or mixed with the feed-water, the product being an oxide of iron—that if the Author meant by this that the oxygen described as dissolved in the feed-water combined alone with the iron, producing pure oxide of iron as in a laboratory experiment, he could not agree with him. No doubt oxygen was a great agent in the corrosion of marine boilers, but it was by no means the sole agent, and its action was conditioned by other substances. The Author appeared to have confined his remarks to the internal corrosion of boilers; but in the case of the boilers of steam-vessels, external corrosion was of at least equal importance, and that corrosion was certainly independent of the feed-water. If pure water, saturated with oxygen obtained from the atmosphere, were fed into a boiler, oxidation would be very slow, and of correspondingly small commercial importance. The oxygen disengaged in the boiler from the feed-water by the process of boiling was mechanically Commodore Isherwood.

Commodore Isherwood. mingled with the steam, which not only occupied the steam-room of the boiler but largely pervaded the water too, the latter being, in fact, more or less in the state of froth. The oxygen thus diluted by the steam lost proportionately its corrosive effect, and had but little chemical action upon the iron surfaces. To illustrate how the action of the oxygen was affected in a boiler by conditions independent of the oxygen, there might be cited the experimentally known fact that, other things being the same, the oxidation was less the higher the temperature of the feed-water. Passing the feed-water through a "heater" on its way to the boiler lessened greatly the corrosive action of that water, by mere increase of temperature. The interior of the shell of a boiler was rarely affected by oxidation; but if a "superheater" was used, its internal surfaces, which were of course at a temperature much higher than that of the shell of the boiler, rapidly corroded, even if the metal was of the same thickness and quality as the boiler-shell. The steam in the boiler-shell and in the superheater would be of course of the same pressure and generated from the same water; the only difference was in the temperature, but that enormously affected in this case the corrosion of the metal. Again, the corrosion of the metal in a boiler exposed to a particular set of influences was greatly affected by the mere thickness of the metal; other things being equal, the thinner the metal the greater the corrodibility. He did not mean by this that the thinner metal would corrode through sooner than the thicker metal—a sufficiently self-evident fact; but that in extreme cases the thinner metal would have become entirely corroded out while the thicker metal showed scarcely any signs of having been attacked. He believed this truth to be universal, whether applied to boilers or to other iron structures. The braces and the stay-bolts of the flat surfaces of boilers were always much more affected by corrosion than the surfaces themselves; in fact, they were frequently found to be nearly corroded through while the surfaces were practically intact; and this difference was due to the small mass of each stay or bolt relative to the mass of the surfaces it braced. The corrosion of braces and stay-bolts in the steam-room and in the water-room of boilers proceeded with equal rapidity, showing that this difference of location was not a factor in the corrosion. The carbonic-acid gas dissolved in the feed-water and the common salt held in solution in that water were potent agents of internal corrosion; more or less organic matter was also present, and its decomposition increased the corrosive action. The feed-water always contained

salts of lime—sulphates and carbonates—in solution, and the decomposition of these conduced to the same result. Without the presence and reactions of these substances, pure oxygen gas in the feed-water would cause little or no corrosion. The internal and external corrosion of marine boilers was a very complex problem, and certainly could not be accounted for by the single factor of the small weight of oxygen gas dissolved in the feed-water. Independently of the quantity of oxygen gas the feed-water might hold in solution, its quality—scarcely to be appreciated by the most refined chemical analysis—had an enormous influence on the internal corrosion of boilers, in many cases destroying the boiler in one-third or one-half the time it would have lasted with better feed-water. The corrosion of steam-boilers was a striking illustration of the impossibility of applying the results of laboratory experiments, made under one set of conditions, to cases under quite different sets of conditions. The only experiments of commercial value were those made on the scale and under the conditions of actual practice; all others misled the uninitiated and were useless to the initiated. Commodore Isherwood.

Where sea-water was used for feeding marine boilers, its corrosive action on iron was so great that, were not the boiler-surfaces protected by the sulphate-of-lime scale formed on them almost immediately it would be impossible to use such water. The oxygen dissolved in the sea-water played but a trifling part, if any, in this corrosion, which was almost wholly due to the alkalies held in solution. In an experiment made in the naval machine shop at Key West on a boiler fed with sea-water from which the salts of lime had been chemically removed, leaving only its other solid constituents in solution, the metal of the boiler was at once attacked in so pronounced a manner that feeding with this so-called purified sea-water had to be discontinued at once. The lime salts were so completely taken out of the water that no scale formed on the boiler-surfaces. With the Author's assertion that the sulphate-of-lime scale formed on the surfaces of a boiler was so poor a conductor of heat that the plate on which it was deposited became overheated and expanded sufficiently to crack the scale and throw it off, he could not agree. He had known heavily-worked marine boilers with scale between $\frac{1}{4}$ inch and $\frac{1}{2}$ inch thick so strongly adherent that nothing but a hammer and chisel could remove it; there were no signs of cracking, and the sea-water had never penetrated to the metal beneath, which was intact as regarded corrosion. The scale, in fact, was a good conductor of heat under the circumstances, notwithstanding its popular

Commodore Isherwood. character to the contrary. Scale could be cracked off the metal by strongly heating the latter in the absence of water, but this drastic method could only be practised at the imminent risk of ruining the boiler. Many years ago, in the case of a very-much-scaled boiler in which the surfaces were inaccessible, he had removed the scale by cracking it off by the quick expansion of the metal beneath, obtained by lighting a fire of shavings in the furnace, no water being in the boiler; but he did not recommend the practice. Neither was he able to agree with the Author's statement that rapid boiler-corrosion had been proved to be due to air forced into the boiler by the feed-pump, which drew the air from the hot well simultaneously with the feed-water. All feed-pumps, without exception, continually did this, and if the fact asserted were true in one case it should be true in all cases, which it notoriously was not, for he had known boilers that were worked under this condition between 20 and 40 years, and which even then were far from being corroded out. If the pumping of air into boilers—and this was always being done to a greater or less extent—produced so destructive an effect, the result would be not only disastrous but remediless. Fortunately the fact was otherwise.

Mr. Maginnis. Mr. A. J. MAGINNIS did not altogether agree with the Author's statement that corrosion of marine boilers was principally due to chemical causes; as after a good many years of careful watching he had come to the conclusion that the main cause of corrosion was the difference of temperature on either side of the plates. For instance, the plates of the furnace referred to by the Author were admittedly parts of marine boilers which corroded quickly along the line of fire-bars. This corrosion, in Mr. Maginnis' opinion, was due entirely to the wide difference of temperature which was experienced by the plate, as the portion of it just above the line of fire-bars must expand in proportion to the temperature of the fire, whereas on the other side of the plate the temperature was only that of the cooler water coming up from the bottom of the boiler. The result was that the surface cf the plate on the water side must be stretched or torn to allow for the expansion on the fire side. Another part of the boiler which gave considerable trouble through rapid wasting was the bottom of the furnace a little farther in than the bridge. Here the intense heat struck downward from the bridge and raised the temperature of the upper side of the plate above that of the water side. Considerable trouble was also caused by the wasting of the stays. This again was also caused by the intense

heat of the flame in combustion-chambers and elsewhere being transmitted into the centre of the stay, whereas at the surface of the stay there was only the temperature of the water, with the result that the surface of the stay had to be stretched to allow of the expansion of the centre portion. He had been strongly confirmed in this opinion by finding that the longitudinal stays which were at the back of the uptakes wasted considerably, whereas those not in the wake of the uptakes were not affected. Acting on the principle that great heat was conducted into the heart of a stay, he had lapped stays with silicate cotton in strips, and by so doing allowed them to attain the same temperature throughout, with the result that the corrosion was altogether stopped. Of course there was no doubt that chemical corrosion did take place in parts, and that air formed an important factor in corrosion; but he did not think the suggestion put forward by the Author, of forming a hot-well between the air-pump and the condenser, was a practical one. Mr. Maginnis.

Mr. F. J. Rowan remarked that, considering the great amount of study which many investigators, over a long period of years, had devoted to the subject of the Paper, it was not surprising that the Author had not been able either to bring forward any new facts or to add materially to existing information concerning it. The classic researches of Robert Mallet, which were embodied in reports made to the British Association,[1] had gone to the root of the general subject of the corrosion of various qualities of iron in both fresh and salt water, and, although the main object which Mallet had had in view was the preservation of iron ships, yet the nature of much of the action which took place in boilers was indicated by his investigations. It must be admitted, however, that engineers remained practically unacquainted with his work and ignorant of its bearing on the difficulties which they encountered as soon as the days of low-pressure steam passed away, until some years after even the publication of the summary of his experiments.[2] Professor Bonsdorf of Helsingfors, long ago, and Professor Crace Calvert of Manchester, about the year 1866, had demonstrated the action and effect of oxygen and carbon dioxide on iron in presence of moisture, and Faraday had drawn attention (in a Report of the Committee of the House of Commons concerning the Holyhead Roads) to the powerful action of the magnesium chloride Mr. Rowan

[1] Report of the British Association for the Advancement of Science, 1838, p. 253; 1840, p. 221; and 1843, p. 1.

[2] Transactions of the Institution of Naval Architects, vol. xiii., p. 90.

Mr. Rowan. in sea-water on iron plates; but these were for some years considered as observations of merely abstract scientific interest. Having been practically engaged during the years 1860–1873 in the construction of the high-pressure marine boilers and engines introduced by his father, Mr. Rowan's attention had been directed to this subject, and (Mallet's work being at that time unknown to him) he had found in the demonstrations of Professor Calvert, previously alluded to, the first clear indication of a clue to the difficulties of corrosion in marine boilers. Corroborative evidence and additional information had soon appeared, principally from researches carried out in Germany, such as those of Wagner, Fischer, Stingl, etc., and by J. Y. Buchanan and others at home; whilst contemporaneous Papers published by various engineering societies had shown by contrast the want of light in the ideas of engineers. The results of his study of the subject had been published in a Paper read before Section G at the meeting of the British Association in 1876,[1] and this Paper covered the entire field which was embraced by the Author's remarks. A year later the third Report of the "Committee appointed by the House of Commons to enquire into the causes of the deterioration of boilers in the Royal Navy" had been issued. It emphasised the facts then already published, but added no fresh suggestions as to the causes of corrosion. For some years after the issue of that report the main interest in the subject had centred in the question of the comparative rates of corrosion in wrought iron and in steel, many Papers dealing with this question appearing in the Proceedings of this Institution and of other societies. The effects of the presence of mill scale, of different kinds of oil, and of different alloys in steel and iron, had also been studied, as well as the range of galvanic action and its causes, and the influence which was exerted by stress of various kinds upon the corrosion of iron and steel. Even the revelations of the microscope as to the physical structure of iron and steel had been laid under contribution in connection with this subject, so that mechanics, chemistry and physics had all been appealed to in the matter, and facts had been accumulated which tend to invalidate some of the Author's theories of the actions which took place in boilers. With regard to the action of the air held in suspension in fresh or distilled water and in sea-water, the Author was right to some extent, because the constituents of the air or gases were the same in both cases, and

[1] Report of the British Association for the Advancement of Science, 1876, p. 229.

must have the same action on iron. He had omitted to notice, however, that, in consequence of the sulphates which it held in solution, sea-water had the power to absorb a much larger volume of carbon dioxide than an equal quantity of fresh water could absorb, and this additional volume of gas was readily given off from sea-water on the decomposition of its sulphates. This of course gave to a given quantity of sea-water the power to do more damage by corrosion than could be done by an equal quantity of fresh water, and it probably explained some of the figures given in the Author's Table I. In fact, the addition of lime (or calcium carbonate), to which he had alluded, would supply the very reagent suited to decompose the magnesium sulphate of the sea-water and liberate the carbon dioxide. In these days, however, it was almost unnecessary to discuss the effects due to sea-water, because it was the aim of all good marine-engineering practice to abolish the use of sea-water in high-pressure boilers; and the great improvement made in evaporators within recent years had done much to render this possible. In water-tube boilers, especially, sea-water was not used, and this fact rendered inapplicable the remarks in which the Author attributed the pitting and wasting that occurred on the inside of heating surfaces to the action of sea-water, so far as all such boilers were concerned. The Author was unfortunately no happier in his account of the decomposition and effect of magnesium chloride. It was true that that salt was decomposed under the influence of a high temperature (even lower than that due to the pressures of steam carried in marine boilers to-day), but it was not necessary, as his theory supposed, that it should be evaporated to dryness for this result to be reached. Moreover, the statement "the plates or tubes where the fire impinges most fiercely are known to attain a temperature far in excess of the temperature of the water in the boiler, even when there is no scale," was directly contrary to all the principles and facts of heat-transmission, and to the results of every reliable measurement of the temperatures produced in boiling-operations. Moreover, if what the Author imagined were to take place, no high-pressure boiler could survive the operation for many hours without bursting, in consequence of the loss of tenacity to which iron and steel were subject at high temperatures. If it were the case that next to the heating surface there was froth, not water, in any boiler, the life of such an abortive apparatus could certainly not extend to years, nor would it be fitting that it should do so. The "theory of corrosion due to frothing" should therefore be dismissed, and not accepted. The Author's account of the effects produced by furnace- Mr. Rowan.

Mr. Rowan. scale, though ingenious, was not in accordance with the ascertained action of that material. The facts of that action had been widely published in the Papers of Mr. W. Parker,[1] Mr. J. Farquharson,[2] Sir N. Barnaby,[3] Prof. V. B. Lewes,[4] etc., and the careful investigations of Mr. Thos. Andrews[5] had made it plain that the prime cause of the mischief due to furnace-scale in contact with iron or steel plates was to be found in galvanic action and not in boiling. Mr. Rowan did not think the substitute for these researches which was offered by the Author in the present Paper would be accepted by any one who had studied the subject. The Author seemed to have written about high-pressure and water-tube boilers whilst he had before his mind's eye only cylindrical marine boilers which were fed either wholly or partially with sea-water, and, in effect, to have mixed up some very diverse conditions of working. He was undoubtedly right in laying stress upon the exclusion of air from the feed-water, and there were few engineers who would not gladly be shown how to prevent it from being dissolved, or, more correctly, from being absorbed by the water. It appeared, however, that the Author under-estimated the difficulty of this problem. It was not known at what rate water which had been freed from air by boiling could re-absorb air on mere surface-contact with an atmosphere containing it, for exact investigations of this action had not yet been made. This was a subject well worth the attention of those who had means and leisure to carry out such investigations, and probably the rate of absorption when ascertained would be found to be astonishingly rapid. The device shown diagrammatically by the Author (*Fig.* 2) had the same aim as the apparatus constructed by Messrs. G. and J. Weir, but, however it might be managed, Mr. Rowan quite agreed that "returning the water from the condenser to the boiler without allowing it the opportunity of dissolving air" was a matter of paramount importance. A scale formed from sea-water was not the best preservative of boiler-surfaces, but there was no reason why a thin coating of lime and magnesia, formed from fresh water, as he had suggested, in his Paper "On Boiler Incrustation and Corrosion,"[6] should

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[1] Journal of the Iron and Steel Institute, 1881, p. 48.
[2] Minutes of Proceedings Inst. C.E., vol. lxv p. 105.
[3] Journal of the Iron and Steel Institute, 1879, p. 53.
[4] Transactions of the Institution of Naval Architects, vol. xxviii., 1887, p. 247.
[5] Proceedings of the Royal Society, vols. xlii., p. 459; xliv. p. 152; xlvi., p. 176; lii., p. 114. Minutes of Proceedings Inst. C.E., vols lxxxii., p. 281; lxxxvii., p. 340; xciv., p. 180; cv., p. 161; cxviii., p. 356.
[6] Report of the British Association for the Advancement of Science, 1876, p. 229.

not be permanently successful. The Author considerably over-estimated the non-conducting power of lime scale unless it was of considerable thickness. The experiments carried out by Mr. Hirsch at the Conservatoire des Arts et Métiers in Paris,[1] and those of Dr. Wiebe and Mr. Schwirhus at the Reichsanstalt,[2] had shown clearly that the effect of non-conducting coatings of moderate thickness was simply to increase the time required for the metal to acquire its static condition for a certain rate of heat-transmission. In boiling-experiments the time required to bring the water to the boiling-point was increased, but afterwards the amount of heat transmitted was not affected, and therefore the plates suffered no undue heating. Although sympathizing fully with the object of the Author's Paper, Mr. Rowan could not conclude his remarks upon it without expressing an emphatic dissent from a part of the Author's closing sentence. There need be no frothing in a good boiler if the water and the boiler were kept clean and there was proper freedom of water-circulation; but whilst it was well that the circulation should be as perfect as possible, the Author's idea of "limiting the fire heat so as to enable the water to wet the heating surface" was, he feared, utterly contrary to all sound principles of economical working which were based upon the correct view of the steam-boiler as a heat-engine. Mr. Rowan.

The AUTHOR, in reply to the Correspondence, remarked, in reference to Commodore Isherwood's statement that the oxidation was less the higher the temperature of the feed-water because it had been proved that a feed-water heater lessened the corrosion, that the effect of heating the water was to separate the air from it; and in all well-designed heaters there was a cock to carry off the air; but even if the air was carried into the boiler it was in larger bubbles and was mixed with, and not dissolved, in the water, so that it was carried off with the steam instead of corroding the boiler. The observation also made that certain thin metal corroded more rapidly than thicker metal, must have been due to a difference in the chemical composition of the plates, and had this condition been reversed the result would have been the opposite. Commodore Isherwood spoke lightly of alkalies held in solution in sea-water without even specifying them, and went on to say that the only experiments of commercial value were those made on the scale and under the conditions of actual practice. If an operation The Author.

[1] Bulletin de la Société d'Encouragement pour l'Industrie Nationale, 1890, p. 302.

[2] *Engineering*, 1 Jan. 1897, p. 31.

The Author. was an experiment it was liable to be destructive as well as preservative: surely Commodore Isherwood would not seriously suggest that experiments should be tried on boilers when they could just as well be tried on iron dishes. The gist of Commodore Isherwood's remarks seemed to be that the corrosion of marine boilers was a very complex problem, whereas his object was to present it as an extremely simple one; so many seemed to forget the plain fact set out in the opening paragraph of the Paper, that all the iron corroded from boiler surfaces was found in the boiler combined with oxygen either as a black or red oxide. There were only two ways of forming oxide in a boiler, one was by the direct union of the iron with the oxygen pumped in as a component of the air, or carbon dioxide could not be formed in this way if there were no oxygen pumped in. When this reaction did not occur, it simply meant there was something to prevent it. His experience of marine and land boilers was that when air was forced into a boiler corrosion was inevitable unless the boiler plates were protected by scale, or there was some chemical action taking place in the boiler that used up the oxygen, such as the action of zinc in salt water and tannate of soda in fresh. The other way of forming oxide of iron had been described in the reply to Mr. Anstey's question, and was frequently referred to as the "frothing" theory. If Mr. Maginnis' theory were correct, all boilers similarly heated ought to corrode to the same extent and powdered iron should be found in the boilers. Air no doubt corroded fastest those stays and plates that were most heated, and the effect of winding silicate cotton round the stay would be to keep the air away and prevent the oxide formed from falling off and exposing a fresh surface of iron. Mr. Rowan's remarks had certainly not tended to simplify the subject. That correspondent complained that in the Paper the corrosion was not attributed to carbon dioxide instead of to air, but this theory was based on mistaken assumptions. Sea-water contained very little carbon dioxide, much less than hard land-water. It did not accord with chemistry to state that carbon dioxide would be liberated by the decomposition of magnesic sulphate and lime. Carbon dioxide acted about the same as air, and when it was eliminated as far as possible, the air corroded as fast as when there was a great deal of carbon dioxide. Mr. Rowan appeared to be firmly convinced that magnesium chloride in solution could be decomposed and would corrode the boiler. The Admiralty Committee proved this was not the case up to 60 lbs. per square inch pressure, and his experiment clearly proved that it was not the case up to 300 lbs.

The Author.

pressure. It was only when evaporated nearly to dryness the magnesium chloride united with water and formed magnesia and hydrochloric acid. If a test-tube containing salt water was held in a flame without shaking it the water took up all the heat until it attained the boiling point. It would then take no more heat from the glass, and supposing the tube to be of uniform thickness and smooth, the water previously wetting it was converted into steam and blew the water out of the tube. Directly the water left the glass the latter became overheated and cracked, and it was manifest that whatever salt was previously dissolved in the water evaporated would remain on the surface of the glass and that the magnesium chloride would produce some hydrochloric acid. Metal surfaces were not uniform enough to produce a similar effect, but if a hole was partly drilled through the metal the water in the hole would attain the boiling point before the surrounding water and a quantity of steam would be given off from the hole. Being anxious to test practically the correctness of his frothing theory he had tried many experiments since the Paper was written. The most successful was one where sea-water was dropped on to a thin plate heated over a Bunsen burner, the amount of heat being regulated to cause the frothing action without coating the plate with scale. The plate was corroded through in 8 hours. These experiments showed that this form of corrosion, and also the formation of scale were both dependent upon the chemical composition of the water at the time and the amount of heat applied to the plate. However Mr. Rowan might interpret the "principles and facts of heat transmission," he must admit that water would not take heat from a plate unless the plate was hotter than the water. When the water had attained the boiling point there was a mixture of steam and water or froth next the plate. If sufficient heat was applied steam would be generated so fast that water would not readily pass it to wet the plate. The circumstances under which water wetted a surface and kept it cool required further investigation; but the margin in boilers was very narrow, as a little oil in the water greased the surface, and the water would not then wet it and the plate became overheated.

6 March, 1900.

SIR DOUGLAS FOX, President, in the Chair.

It was announced that the Associate Members hereunder mentioned had been transferred to the class of

Members.

WILLIAM CHARLES COPPERTHWAITE.
ALEXANDER FARQUHARSON FOWLER.
WILLIAM HENRY FOWLER.
WALTER BERNARD HOPKINS.
WILLIAM KIDD.
DAVID LYELL.
SAMUEL LEES MURGATROYD.
ALFRED PEARCE.

And that the following Candidates had been admitted as

Students.

HERBERT AMBROSE COPE.
HENRY JAMES DEANE.
GERALD THORNHILL EDWARDS.
EWAN MAITLAND GRANT.
JOHN HADDIN.
PHILIP RUFFORD HEWLETT.
ARTHUR GERALD HOUNSFIELD.
CHARLES MATTHEW NORRIE.
THOMAS WILLIAM THOMPSON, B.A. (*Cantab.*)
WILLIAM JOHNSON THORNHILL.

The Candidates balloted for and duly elected were: as

Members.

GEORGE WILLIAM CATT.
NEVILLE EVANS.
ARTHUR HARRY HAIGH, B.Sc. (*Victoria.*)
ALPHONSE STEIGER.

Associate Members.

THOMAS BALLANTYNE.
ALBERT ASHLEY BIGGS.
CHARLES MARCUS BLES, M.Sc. (*Victoria.*)
GEORGE ROBERT DAVENPORT.
HENRY VERRALL FAULCONER.
SYDNEY NEWTON GLASS.
ALFRED WOODS HANCKEL, M.Sc. (*Victoria*), Stud. Inst. C.E.
WILLIAM HENRY MAXWELL.
JAMES RICKMAN, B.A. (*Cantab.*), Stud. Inst. C.E.
ERNEST HEADLY SPRAGUE.
ROWLAND WADE, B.A.I. (*Dubl.*)

An Associate.

CHARLES HENRY DRIVER.

The Discussion on the Paper by Mr. John Dewrance on "Corrosion of Marine Boilers" was continued and concluded.

13 March, 1900.

SIR DOUGLAS FOX, President,
in the Chair.

(*Paper No. 3206.*)

"A Short History of the Engineering Works of the Suez Canal."

By Sir CHARLES HARTLEY, K.C.M.G., M. Inst. C.E.

OWING to the circumstance that no special account of the Suez Canal has been presented to the Institution since Sir William Denison's Paper in April, 1867,[1] 2½ years before the opening of the Canal, it has been considered that a second Communication on the same important subject brought down to the present time would not be unacceptable to the Institution.

The chief object of this Paper being to give a brief account of the recent enlargement of the Suez Canal, comparatively little space can be devoted to a recital of its general history. As an Introduction to the main subject of the Paper, however, it seems desirable to refer in some slight detail to the principal engineering features of the original work, as well as to certain financial difficulties with which the Canal Company had to contend up to the time of its acknowledged success as the greatest commercial enterprise of the century.

Mean Level of the Red Sea and Mediterranean.—The first idea in modern times of a ship-canal across the Isthmus of Suez was conceived by Napoleon I., but the scheme was abandoned as impracticable when Lepère reported that the surface of the Red Sea was 30 feet higher than that of the Mediterranean—a fallacy which was not exploded until 1847, when a series of levels established the identity of the mean sea-levels at Suez and Port Said.[2]

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[1] Minutes of Proceedings Inst. C.E., vol. xxvi. p. 442.

[2] The difference in level between ordinary high and ordinary low water at Suez is 3 feet 9 inches; at Port Said 9 inches. The extreme difference, caused by contrary winds, observed at Suez is 8 feet 6 inches, and at Port Said 4 feet 6 inches. The prevailing winds are from north and north-west.

Concession of the Canal to Ferdinand de Lesseps in 1854.—In November, 1854, Ferdinand de Lesseps, the illustrious founder of the canal, obtained a concession from Said Pasha for a waterway from sea to sea without locks, and in October, 1855, an International Consultative Commission, selected from among the most celebrated hydraulic engineers in Europe, was appointed to report on the scheme (Appendix No. I.).

Report of the International Consultative Commission of 1855–56.—The final Report of the Consultative Commission, which was framed after a Sub-Commission, consisting of five members, had visited Egypt and had studied the question on the ground, was submitted to and accepted by the Khedive in June, 1856. Its chief resolutions and recommendations were to the following effect:—It rejected the system of indirect routes through the Delta of the Nile, and adopted the principle of a direct route through the Isthmus from Suez to the Mediterranean. It discussed the advantages and drawbacks of a canal with continuous banks, and decided that there should be no embankments where the canal passed through the Bitter Lakes. It expressed the opinion that locks at the two extremities of the canal would not be necessary, as the lakes would have the effect of deadening the tidal currents. It stipulated that the depth of the canal should be 8 metres (26¼ feet), and wide enough not only to allow two vessels to pass each other, but to give room for a third line of vessels which might, from any cause, stop on the way; and it was therefore recommended that the canal, between the Red Sea and the Bitter Lakes, should have a width of 210 feet at the bottom, and of 320 feet at the top; and that the channel between the Bitter Lakes and the Mediterranean should be cut to a width of 144 feet at the bottom, and to 262 feet at the top; and, lastly, the Consultative Commission decided on the plan of running out jetties directly seaward at Port Said to protect the entrance, rather than at a point 15 miles to the S.E., on the shore of the Gulf of Pelusium, the entrance originally proposed by the engineers of the Khedive. The ultimate choice of the entrance (thanks to the representations of Mr. Larousse, hydrographer of the French navy), although necessarily involving the construction of a considerably longer artificial waterway across the Isthmus, was based on the important consideration that a depth of 8 metres was found at a distance of less than 2 miles from Port Said, whereas at the proposed easterly entrance, near the old Pelusiac mouth of the Nile, the 8-metre contour was fully 5 miles from shore. When it is remembered that the cost of jetties built on a

shallow, sandy coast is nearly in proportion to their length, and that a steep slope of the sea-bed fronting a seaport is a great advantage, it can hardly be doubted that the final decision in favour of Port Said was a wise one.

At Port Said the direction and length of the jetties, as well as their mode of construction, was subsequently adopted on the advice of Mr. Pascal, Inspector-General of Roads and Bridges, whose death in 1896 was so greatly deplored by his old colleagues. At Suez, Port Thewfik, the construction of a single jetty was deemed sufficient, and no difference of opinion existed as to the disposition of the necessary inner harbour works at each end of the canal. The lengths of the west and east jetties at Port Said are 9,800 feet and 6,000 feet respectively. The width between them at their origin is 4,200 feet, and their distance apart at the end of the east jetty is 2,300 feet. The width and depth of channel alongside the west jetty are 330 and 30 feet respectively, and the direction of the channel is N.E. by $\frac{3}{4}$ N.

Formation of the Suez Canal Company in 1858.—The resolutions of the Consultative Commission were widely published, and produced such a favourable effect on the public mind that at the close of 1858 Mr. de Lesseps succeeded, in spite of the then determined opposition of the British Government, in organizing a company to carry on the work. Besides the founders' shares, the total number of ordinary shares of the company was 400,000 of £20 each, of which French investors took nearly three-fifths and the Khedive rather more than two-fifths. Thus the original capital of the company, when all the ordinary shares were allotted, was £8,000,000 —the sum named by the Sub-Commission and by the Engineers of the Khedive, Mougel Bey and Linant Bey, as being sufficient to cover the cost of the canal and all the works connected with it.

Topography of the Canal (Figs. 1, 2, 3 and 4, Plate 2).—The construction of the canal was greatly facilitated by the existence of four dried-up depressions which were formerly and have again become lakes of considerable area, namely, the two Ballah Lakes, the Great and Small Bitter Lakes, and Lake Timsah. These low-lying regions have an aggregate length of 27 miles. Excavation was required, however, throughout the Ballah Lakes, Lake Timsah, and the Small Bitter Lake, as well as along a portion of the Great Lake; and, consequently, it was only for a length of about 8 miles of the latter, where the natural depth exceeded that of the canal, that no excavation was necessary.

The distances between Port Said and these lakes are as follows:—

		Nautical Miles.
Port Said to North end of Lake Ballah	. . . .	26
„ „ South „ „ „	. . . .	30
„ „ North end of Lake Timsah	. . . .	41
„ „ South „ „ „	. . . .	44
„ „ North end of the Bitter Lakes	. . . .	53
„ „ South „ „ „ „	. . . .	73

The total distance from Port Said to Suez, Port Thewfik, is 88 nautical miles (100 English miles) or 160 kilometres.

The only serious obstacles to be overcome in the line of the canal were at El-Guisr, the summit of the work, situated between the Ballah Lakes and Lake Timsah, where the hills crossing the canal vary from 30 feet to 60 feet above the sea-level over a length of 6 miles, and at the deep cutting of Serapeum between Lake Timsah and the Great Bitter Lake. From Port Said to Kantara, a distance of 24 miles, the canal passes through Lake Menzaleh, a shallow lagoon which covers an area of nearly 1,000 square miles.

The character of the soil, which is mainly composed of pure sand and sandy-clay lying above and below a nearly continuous stratum of hard clay abutting, for the most part, on the water-line between Lake Menzaleh and Lake Timsah—intersected here and there by bands of hard and soft rock (conglomerate and limestone) between Serapeum and Suez—was favourable to rapid execution; and the construction at Port Said and Suez of commodious basins for shipping, and of the long sea jetties, composed of "pierres-perdues" and artificial blocks of concrete, thrown down at random to a height of 4 feet above the water-line, presented no serious engineering difficulties. In short, the canal works in general were of a very simple nature; but, being of vast magnitude, involving, as originally proposed, the removal of 60 million cubic metres of dry earthwork and 56 million cubic metres of earthwork under water, and being situated in a country entirely destitute of fresh water, a specially well-conceived organization was imperatively required to bring the colossal work to a successful issue.

Commencement of the Works.—On the 25th April, 1859, Mr. de Lesseps, President of the newly-formed company, turned the first spadeful of sand at Port Said. Early in March, 1861, the Author, who was kindly furnished by Mr. de Lesseps with letters of introduction to the principal employees of the company, visited all the works between Ismailia and Port

Said;[1] and immediately after his inspection furnished the British Government, at the request of the British Consul-General for Egypt, with his notes of travel across the Isthmus, accompanied by the expression of his own opinion as to the entire practicability of the scheme, the successful realisation of which, he stated, was but a question of time and money; the reduction of these items being dependent on the substitution of efficient steam-dredgers and other improved mechanical appliances for hand-labour.

At the time of his visit not a fiftieth part of the earthwork of the canal proper had been removed—a condition of affairs due to financial difficulties; to a great paucity of labourers; to the difficulty of providing them with fresh water; to the faulty construction and inefficiency of the steam-dredgers then employed; to the impossibility of keeping open the newly-dredged entrance channel at Port Said before it was protected by the jetties; and especially to the necessity for first of all constructing a fresh-water canal from Cairo to Suez by way of Ismailia, and for laying down duplicate iron pipes from Ismailia to Port Said, so as to insure a constant and ample supply of drinking-water for the workmen along the whole length of the canal.

Accelerated Progress after 1862.—As the work progressed, these difficulties were gradually surmounted, thanks chiefly to the skill and resource of Voisin Bey, the first engineer-in-chief, and his able assistant engineers, Messrs. Laroche, Larousse and Gioia; and to the provision by Mr. Lavalley, the contractor, of a large fleet of powerful dredging-machines, by means of which the dredged material, carried by long and high projecting shoots, was rapidly delivered on either bank of the canal at some distance from the slopes of the cuttings without the intervention of barges. These and other mechanical appliances had the effect of reducing by three-fourths the number of workmen needed to open the canal by the time originally estimated; whilst the completion of the fresh-water canal in 1863 relieved the company of the enormous expense of supplying the workpeople with water brought from the Nile on camel-back. In July, 1862, the Khedive requested Mr. (afterwards Sir John) Hawkshaw to examine the site of the proposed Suez Canal and to report thereon. Accordingly, at the close of that year, Mr. Hawkshaw minutely inspected

[1] At this time Port Said was simply a collection of hovels situated on a narrow belt of dunes separating Lake Menzaleh from the sea. To-day (1900) it is the largest coaling station in the world, with a population of 40,000 souls, of whom 11,000 are of European descent.

the whole length of the canal, and shortly afterwards, in summing up his long and convincing report, addressed to the Egyptian Government, expressed his belief that the canal could be made and could be maintained at a moderate and reasonable expense.

Increase of Capital and reduced width of Canal.—The financial difficulties were overcome:—(1) by decreasing the width of the bottom of the canal to 22 metres (72 feet), *i.e.* less than one-half the width recommended by the International Consultative Commission, it having been found soon after the works were begun that the cost of the work had been greatly under-estimated; (2) by virtually increasing the original capital of £8,000,000 to £17,120,000, thanks to the Emperor Napoleon's award of £3,800,000,[1] and to subsequent loans amounting to £5,320,000.

As some compensation for the greatly reduced area of the canal, "gares" or sidings were provided at every 5 or 6 miles between Port Said and Lake Timsah to allow vessels to bring up either for the purpose of passing each other, or to moor for the night.

In April, 1867, water from the Mediterranean was let into the marshy bed of Lake Timsah, but it was not till March, 1869, that it was allowed to flow into the nearly dry salt-encrusted basins of the Bitter Lakes.

Opening of the Canal.—On the 17th November, 1869, the Suez Canal was inaugurated with great pomp and thrown open to navigation.

Total Cost of the Work up to 31st December, 1869.—On the 31st December following, forty-four days after the opening of the canal, when in several places the depth was less than 20 feet over a width of 60 feet, the cost price was stated in the "Bulletin décadaire," No. 22, as follows:—

	£
General expenses of the constitution of the company, cost of negotiation, commission, stamps, and expenses as to shares	561,380
Cost of management for 11 years	567,300
Interest during construction, including sinking fund	3,316,520
Service of health, telegraph, domain, and transit, 1868–1869	533,530
Cost of construction, including sinking fund to pay for materials	11,654,223
Total	£16,632,953

[1] This sum was paid by the Khedive to the Company as indemnification for the loss it would sustain by the withdrawal of forced, or corvée labour; for the retrocession of land grants; and for abandonment of other privileges attached to the original concession.

Financial difficulties and Tonnage Question.—It would require many pages to describe in detail the serious pecuniary difficulties of the company from the opening of the canal up to the time when the revenue from dues on shipping began to increase by leaps and bounds. The limits of a short Paper also forbid more than a passing allusion to the burning question which was then under discussion, relative to the claim of the company to its right to levy dues on the gross register tonnage instead of on the net register tonnage of ships, and to a re-adjustment of the tariff. The following summary of facts regarding the tonnage question should be premised by the remark that, in the concession by the Khedive in 1856, it was expressly stipulated that the tariff on shipping passing through the canal was to be the same for ships of all nations, viz., 10 francs per ton, and 10 francs per passenger. According to this understanding, from the opening of the canal to the 1st July, 1872, the transit dues were levied at the rate of 10 francs on the net registered tonnage; but from that date to the 29th April, 1874, notwithstanding the protests of the shipping interest, the rate of 10 francs was levied on the gross registered tonnage. In 1873 the International Tonnage Commission defined the mode of measuring the gross tonnage of a ship, and the deductions to be made therefrom to arrive at the net tonnage, which was declared to be the tonnage on which alone the dues could be levied. At the same time a surtax of 3 francs was recommended and adopted by the Powers which raised the toll from the 10 francs of the original concession to 13 francs per ton, which was to be reduced to 10 francs as traffic increased. By a subsequent convention made in 1876 a modification was made in the terms of reduction by which ½ franc per ton was taken off at fixed dates, being on the 1st January of the years 1877, 1879, 1881, 1882, 1883 and 1884. On the 1st January, 1885, under an agreement with the English shipowners, the rate was reduced to 9½ francs, and under the automatic action provided by that agreement the dues were again lowered on the 1st January, 1893, to 9 francs per ton, at which rate they still remain.

Purchase of Shares by the British Government.—The remarkable episode of the purchase by the British Government in 1875 of the Khedive's shares should not be passed over unnoticed, even in the barest account of the financial vicissitudes of the canal. It should first be remarked that the 400,000 original £20 shares of the company had yielded no surplus whatever over the fixed 5 per cent. till 1875, and that the Khedive had at that time mortgaged till 1894 the interest on the shares held by him.

In 1875 the British Government purchased for the sum of £4,000,000 the 176,602 original shares which belonged to the Khedive. This famous purchase was based in a great measure on the advice of Lieutenant-General Sir John Stokes, K.C.B., Ex-member of the International Tonnage Commission of 1873, and since 1876 one of H.M. Representatives on the Board of Directors of the Suez Canal. The main results of this memorable transaction were concisely stated by the Chancellor of the Exchequer when he informed the House of Commons on the 19th June, 1893, that the total estimated value of the Suez Canal shares purchased by Lord Beaconsfield in 1875 for £4,000,000 was then £17,750,000;[1] that £3,805,000 out of £4,000,000 had been paid off by the sinking fund; that the shares purchased would be entitled to a dividend on the 1st July, 1894; that the amount of the dividends paid by the company for the past three years had been 17, 21 and 18 per cent. respectively, and that the ratio which British tonnage bore to the total tonnage of ships passing through the canal was 75 per cent.

Dredging and Maintenance.—According to the official statistics, made up to the 31st December, 1882, the dredging and excavation work for the maintenance of the canal and basins from November 1869 up to and including 1882, had been 13,600,000 cubic metres (exclusive of 1,800,000 cubic metres for enlargements), and according to the annual statistics of the company for 1897 the amount of dredging required for maintenance pure and simple from 1875 to 1897, both inclusive, had been 31,064,839 cubic metres, distributed as shown in the Table on p. 165. When it is considered that the cost of dredging averages upwards of 1*s.* per cubic metre, the heavy annual charge incurred for maintenance becomes at once apparent.

Enlargement of the Canal.

Rapid Increase of the Traffic since 1872.—The events which led to the enlargement of the canal, the first phase of which was virtually completed last year, should now be referred to in some detail. The "Compte Rendu" of the company, from 1869 to 1883 inclusive, showed that in 1872, when the number of ships passing through the canal was 1,082, with an aggregate registered net ton-

[1] At the present market value of £150 per share the actual value of the shares held by the British Government is £26,500,000.

nage of 1,160,000, the receipts were £575,000, as compared with 3,307 ships and a net tonnage of 5,776,000 tons, and receipts of £2,422,000 in 1883. The same Table further showed that whilst in 1870 the average registered tonnage was only 897 tons per vessel, in 1875 it was 1,345 tons, and in 1883 1,740 tons per vessel.

It also appeared by other statistics published by the Company that the average time occupied by vessels in the canal had risen from 39 hours in 1876 to 48 hours and 40 minutes in 1883.

Locality.	1875–1882 (8 Years).	1883–1897 (15 Years).	Total in 23 Years.	Average per Annum from 1883–1897.
	Cubic Metres.	Cubic Metres.	Cubic Metres.	Cubic Metres.
Dredging at Port Said.				
Along the east side of the west jetty	37,898	2,168,248	2,206,146	144,550
In the channel of the Avant Port	2,005,365	2,101,044	4,106,409	140,136
In the basins	356,605	1,203,836	1,560,441	80,259
Seaward of the jetties	1,332,716	3,660,602	4,993,318	224,040
Dredging between Port Said and Suez.				
Port Said section	3,390,621	6,577,597	9,968,218	438,510
Ismailia section	1,178,259	3,051,072	4,229,331	203,405
Suez section	1,283,088	2,717,888	4,000,976	181,192
Total	9,584,552	21,480,287	31,064,839	

Owing to this increased delay in the passage of steamers through the canal since 1876, and to the startling augmentation of traffic since 1872 (resulting principally from the adoption of iron steamers in the Red Sea route to the Far East, and from the great economy of fuel effected by the employment of screw-propellers worked by triple-expansion engines—an economy in transport which was unforeseen when the concession for the canal was obtained), it was universally admitted in 1883 that a radical plan of improvement was imperatively demanded, in order to remove the numerous delays which at that period impeded the passage of a swollen navigation through a restricted waterway.

Constitution of a Second International Consultative Commission 1884–85.—This opinion caused the Directors of the Company, at their annual meeting in May 1884, under the presidency of Mr. Ferdinand de Lesseps, to announce to the shareholders—after reminding them that, under his convention with the British

Government of 1876, a special sum of £1,200,000 had been already voted and partly expended on indispensable improvements —that a second International Consultative Commission, consisting of eight Frenchmen, eight Englishmen, and six members of other nationalities (Appendix No. II.), had been appointed to study the question as to the best means to be employed either to enlarge the present canal sufficiently or to construct a second canal alongside the existing one, with the object of eventually providing ample accommodation for a traffic exceeding 10,000,000 tons a year.

The Consultative Commission met in Paris, and held three sittings in the latter part of June 1884, when, after discussing two alternative schemes presented by the Engineer-in-chief of the canal, Mr. Lemasson (one for the enlargement of the existing channel, and the other for an independent parallel channel), it was decided that eight members of the Commission should act as a Sub-Commission and visit Egypt; in order to make such observations and investigations on the spot as would ultimately enable the Commission to arrive at a final decision on the important question of the best means of preventing delays in the passage between the Mediterranean and the Red Sea, and *vice versâ*, and of providing for the expansion of trade.

Sub-Commission of 1884–85.—The Sub-Commission was composed of the following Members:—

France	Messrs. Voisin Bey and Tillier.
Great Britain	Sir John Coode and the Author.
Germany	Mr. Pescheck.
Austria-Hungary	Mr. Crillanovich.
Italy.	Mr. Gioia.
Holland.	Mr. Dirks (President).

"Reporter," Mr. Voisin Bey. Secretary, Mr. Vieussa.

Projects of Mr. Lemasson.—Before referring more particularly to the doings of the Sub-Commission, reference should be made to the projects of the Engineer-in-chief of the Company. It has already been noticed that he presented two schemes for an improved waterway, and inasmuch as his project for the pure and simple enlargement of the existing waterway was accepted with but few modifications by the Sub-Commission, and eventually by the Directors of the Canal, the main features of that scheme should now be described.

In explaining the details of this project, the execution of which he recommended should be divided into three stages, Mr. Lemasson contended that the waterway should be wide enough

for two steamers to pass each other in motion without danger of collision; and to accomplish this he was of opinion that there should be a space equal to two clear beams between them, and an interval of 12 metres (40 feet) between their outer sides and the lines of buoys. This meant a channel—taking 48 feet as a maximum beam—of about 70 metres (230 feet) broad at the bottom, which he considered would be sufficient for the long straight reach south of Port Said; whilst for the Suez end and for the curves, he proposed to increase the breadth to 80 metres (262 feet). The total cost, including plant, was estimated at £8,118,000 if the depth were kept at 8 metres (26¼ feet), or £9,750,000 if increased to 9 metres (29½ feet).

The cost of a parallel canal having a depth of 9 metres was estimated at £11,150,000, but this merely served for the construction of a new channel of the same width as the existing one, and no allowance was made for sidings, nor was any sum included to represent the capitalized value of the great increase of the working expenses which the execution of a second canal would undoubtedly entail.

Visit of the Sub-Commission to Egypt in 1884.—The members of the Sub-Commission, accompanied by Mr. de Lesseps, Mr. Charles de Lesseps, Mr. Anslyn (a Director), and Mr. (now Sir James) Laing (a Director), assembled at Port Said on the 21st November, 1884, and were joined by Mr. Lemasson and the other "Chefs de Service" of the Company, all of whom gave the Sub-Commission every possible assistance during its fortnight's inspection of the ground.

Information Collected by the Sub-Commission during its Inspection of the Isthmus.

As one of the principal objects of the mission confided to the Sub-Commission was to ascertain on the spot the opinion of captains of large steamers frequenting the canal, and of experienced pilots in the service of the Company regarding the question of a safe width and depth of waterway to allow the meeting of two vessels in the Canal, both being under way; the Commission drew up a list of questions bearing on this important matter, and submitted it for the consideration and remarks of nine captains of the largest-sized steamers navigating the canal, and to twenty-five of the most skilful pilots of the company.

Opinion of Experts as to the adequacy of the proposed enlarged Canal.—The following answers of these experts to some of the

questions put to them, practically confirmed the sufficiency of the dimensions of the transverse section of Mr. Lemasson's project for the eventual widening of the canal threefold from Port Said to Suez.

First Question.—In a canal three times larger at the bottom than the present one in its straight parts and without currents, and three and a half times wider in the curves and where currents exist, could two large vessels in motion pass each other in safety?[1]

Replies.—Thirty-two replied in the affirmative, and two demanded a width of 76 metres and 80 metres respectively.

Second Question.—How much water should a large vessel have under her keel to enable her to steer well at a speed of 8 knots an hour?

Replies.—The answers varied from a minimum of 6 inches to a maximum of 6 feet under the keel, but the average depth demanded by the captains was 3½ feet, and by the pilots 3 feet.

Third Question.—At what speed could large vessels steam through an enlarged canal, with a sufficient depth under their keels?

Replies.—Eight estimated a speed of 7 knots, twelve of 8 knots, and the remainder of about 10 knots an hour; the estimated average of all the experts being 8 knots.

Fourth Question.—At what distance from each other should vessels begin to slacken speed in an enlarged canal?

Replies.—Eight captains and seventeen pilots demanded 1 mile, and one captain and eight pilots demanded 2 miles.

Fifth Question.—What should be the speed of each vessel at the moment of passing the other?

Replies.—Seven captains and twenty-one pilots were of opinion that the speed of each vessel should be as slow as possible, and the remainder considered that they could pass each other safely at speeds ranging from 2½ knots to 4 knots an hour.

Sixth Question.—At the meeting of two vessels in motion what should be the distance between them?

Replies.—Six captains and seventeen pilots demanded a distance of 1½ times the beam of a vessel, and the remainder of from ½ to 1½ times the beam.

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[1] Between Suez and the Bitter Lakes the current ranges from ½ knot to 2 knots an hour. Between the Bitter Lakes and Port Said there is practically no current.

Experiences of the Sub-Commission, during the Inspection of the Canal.—In addition to obtaining the opinion of competent persons on the spot, the members of the Sub-Commission had several opportunities of judging for themselves, during their close inspection of the canal, how best to provide increased facilities of transit, not only for the time being, but for many decades to come.

On board the s.s. "Austral."—The limits of this Paper, however, will only permit reference in anything like detail to certain experiences on board the Orient Company's s.s. "Austral," which, at that time, was the largest steamer that had passed through the canal. The "Austral" has a length of 456 feet, a beam of 48 feet, a gross tonnage of 5,665 tons, and a draught of 27 feet when fully loaded. Her actual draught aft in navigating the canal was 24 feet 6 inches (7 metres 50 centimetres), the maximum immersion then allowed by the canal company, and consequently, with this limited draught, she could only load up with half her full complement of coal. On the 26th November, 1884, the "Austral," on her arrival at Lake Timsah from Port Said, was boarded by the Sub-Commission, after she had cleared the Timsah bend by the aid of warps, an operation which took 40 minutes to perform, as the radius of the curved channel at that spot was then only 3,000 feet.[1] In the straight part of the canal, after leaving the lake, she steamed at the regulation pace of 5½ knots (10 kilometres) an hour to the curve at Toussoum, where her speed was slackened to 4 knots. Thence she resumed the maximum regulation speed as far as the "Déversoir" siding, where she again slackened speed to pass a couple of large steamers lying moored to the bank within the siding. Here, as on several other occasions, the Commission noticed the attraction of the moored vessels towards the passing steamer; in other words, at the moment a vessel in motion passed a vessel moored to the bank, the latter was invariably drawn towards the passing vessel; the amount of the disturbance being proportional to the speed of the passing ship.

The distance of 8 miles between the north and south lighthouses of the Great Bitter Lake was accomplished at the rate of 13 miles an hour. The "Austral" then passed through the Little Bitter Lake, where the bottom had already been widened from 22 metres to 40 metres. She then stopped at the seventy-first milepost in order to allow four vessels coming from Suez to enter the siding

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[1] The radius of this curve was originally only 300 metres. Many years since the radius was increased to 4,100 feet, over a width at the apex of 700 feet.

at Chalouf at the seventy-fifth milepost. This siding had been formed by a widening of 15 metres on each side of the channel over a length of 750 metres; and here, as in all the other sidings between the Bitter Lakes and Suez, the passage was frequently made without difficulty between two ranks of vessels moored to the bank within the sidings.

After a stoppage of 70 minutes, the time required for the mooring of the four vessels, the "Austral" continued her voyage, passing the four shunted steamers at the rate of 3 miles an hour with a clear width of 60 feet of empty space on each side; and finally came to anchor in the roadstead of Suez after a passage of 8 hours 35 minutes (deducting the time lost at Chalouf), which is equal to a mean speed of 5 knots an hour, with a tide from the Bitter Lakes of about half a knot an hour in her favour.

Before taking leave of the "Austral," it should be remarked (as illustrating in a striking manner the retarding effect of friction on the speed of large vessels navigating a restricted channel) that the "Austral," in passing through the straight reaches of the canal between Lake Timsah and Suez, only made 5 knots an hour with 43 revolutions of her screw; whereas in the open sea with the same number of revolutions (43) she made 11 knots, and with 68 revolutions 16 knots an hour.

Condition of the Canal in 1884.—In order to ascertain the condition of the canal-banks, and to test the effect produced on the revetted and unrevetted slopes by passing steamers, the Commission had a powerful steam-tug placed at its disposal with a view to facilitate its task.

Revetments.—Between Port Said and El Guisr, and throughout the Suez plain, the upper parts of the slopes, down to depths varying from 3 feet to 9 feet below the water-line, were being gradually protected at the time of the inspection with smooth-faced masonry in hydraulic mortar, laid at inclinations at from 2 to 1 to 5 to 1, according to the nature of the ground, and it was observed that throughout these portions of the canal the banks had been severely attacked and eroded, notwithstanding the various methods that had been employed to protect them from the wash of the waves generated by steam-vessels. These methods consisted of revetments of riprap in moderately solid ground, of dry rubble disposed in steps supported by piling in soft ground, and by a pavement of masonry where the banks consisted of stiff clay.

In the cuttings of El Guisr and Serapeum the slopes above the

water-line were found to be sufficiently protected by continuous plantations of tamarisks, reeds, and similar plants, and the submerged slopes of these long and deep cuttings—where the surface width of the canal was barely 200 feet, as compared with the surface width of 320 feet between Port Said and Kantara and elsewhere—were also found to be in excellent condition.

With regard to the effect produced on the slopes by the waves which followed the run of vessels in motion, the Commission invariably found that wherever the slopes were abnormally flat and the submerged benchings were inordinately wide, the waves oscillated to mid-channel, and broke heavily on the banks, thus acquiring a movement of translation, and that under this double action the upper parts of the slopes, where unprotected, were rapidly shorn down and swept away; and that even the stone revetments were not infrequently either damaged or partially destroyed.

On the other hand, it was observed that in the regions of the canal where the submerged slope prolonged itself to the water-line (and was, therefore, without a benching of any kind, as at El Guisr), the waves broke lightly and seemed to have no destructive force. At the same time, however, it was apparent that this immunity from damage was not a little due to the plantations at the water-line having the natural effect of deadening the action of the waves without injury to the yielding and well-rooted plants which at El Guisr border the waterway along both banks.[1]

Electric Light Experiments in 1884.—The Commission, before completing its inspection of the works, had also the opportunity of taking part in one of the night experiments which were then being made by the chief executive officers of the Company on board a steamer carrying a 1,600 candle-light at a height of 18 feet above the water-level, in view of the contemplated illumination of the whole length of the canal by means of electricity. On the occasion referred to, the experiments were made in a part of the canal where the buoys were disposed in pairs at intervals of 500 metres; the width of channel between the two lines of buoys being 34 metres.

The Commission found that at the moment of passing a pair of buoys, but not till that moment, the following pair of buoys became distinctly visible, and owing to this circumstance it was considered desirable that the pairs of buoys should be placed at

[1] The question of the best type of cross-sections for canals in general, and especially for the Suez Canal, is discussed at length in Mr. Conder's Paper on "Speed on Canals," Minutes of Proceedings Inst. C.E., vol. lxxvi. p. 160.

intervals of only 250 metres in order that a vessel might always have two pair in view—an indispensable condition to insure a proper direction in navigating a contracted waterway. At this period no one ventured to predict that in less than five years' time the result of these early experiments would have the effect of virtually doubling the carrying capacity of the canal, independently in a great measure of additional engineering works.

Final Meetings of the Sub-Commission.—The members of the Sub-Commission, having completed their labours on the ground, held several subsequent meetings in Egypt and Paris before submitting the result of their proceedings to the judgment of their colleagues in the International Consultative Commission.

Resolutions of the Consultative Commission in 1885.—On the 11th February, 1885, all the members of the full Commission reassembled at Paris, and unanimously adopted the following resolutions in favour of an enlarged canal:—Concerning the choice of methods to be adopted for the enlargement of the waterway, the Commission gives unqualified preference to the system of a pure and simple enlargement of the canal, from the Mediterranean to the Red Sea.

As to the dimensions of the enlarged canal:—

1. As to the depth, the Commission is of opinion that the project for the works and estimate of cost should comprise a final deepening of the canal to a depth of 9 metres (29 feet 6 inches) below the level of low water of ordinary spring tides at every point; but at the same time the Commission thinks that the programme for the successive execution of the work should be fixed with the object of first obtaining a depth of 8·50 metres (27 feet 10 inches); the complementary deepening of 0·50 metre (1 foot 7 inches), being the last phase of the execution of the projected improvement.

2. As to the widths of the canal and the easing of the curves, the Commission is of opinion that the canal should have the following widths at the depth of 8 metres (26 feet 3 inches) below the level of low water of ordinary spring tides, that is:

A. Along the portion of the canal between Port Said and the Bitter Lakes:

In straight reaches, a width of 65 metres (213 feet). In curves of more than 2,500 metres (8,200 feet) radius, a width of 75 metres (246 feet), measured at the apex of the curve adjusted gently to the normal width of the canal; and, lastly, in curves of 2,500 metres (8,200 feet) and less radius, a width at the apex of at least 80 metres (262 feet).

B. Along the portion of the canal between the Great Bitter Lakes and Suez:

In straight reaches, a width of 75 metres (246 feet). In the curves, a width of 80 metres (262 feet) at the apex.

As to the curve in the Timsah Lake, to increase its radius to 1,250 metres (4,100 feet), and to begin its correction without loss of time.

3. As to the harbour of Port Said, the Commission approves of the reduction of the width of the Asiatic island between the coaling dock and the Ismail dock, and of the rectification of the curve at the first milepost to a radius of 3,000 metres (9,843 feet).

Concerning the typical sections of the canal, the Commission is of opinion that it is necessary to include the protection of the canal banks against erosion in the project for the completion of the canal. The Commission, moreover, thinks that this protection of the banks is not indispensable in the first instance, and is only necessary throughout the Menzaleh and Ballah Lakes and between the small Bitter Lakes and Suez.

Among the different types of protection works already employed, the Commission would prefer (wherever the nature of the ground allows its application) a stone pitching in mortar laid at as steep a slope as possible in favourable ground, reaching down to 2 metres (6 feet 6 inches) below the level of low water of ordinary spring tides, resting on a benching of a width just sufficient to insure a solid base for the work, and rising to a height of about 1 metre (3 feet 3 inches) above the level of high water of ordinary spring tides.

Lastly, the Commission thinks that the typical sections drawn up by the Engineer-in-chief of the company in conformity with the above indications should be definitely accepted. The past, present and proposed cross sections are shown respectively in Figs. 7, 8, and 9, Plate 3.

These recommendations were signed by all the members of the Consultative Commission, and were accepted soon afterwards by the President and Directors of the Suez Canal Company.

Bases on which the Recommendations of the Consultative Commission were made.—It is impossible within the limits of a short Paper to give anything like an adequate account of the grounds on which the Consultative Commission of 1884–85 arrived at the above-mentioned decisions. Sufficient space, however, must be found to allude briefly to the following important elements which naturally came prominently to the front in the final discussions at the meetings of the Sub-Commission at Ismailia, before the conclusion of its labours in Egypt.

1. Question of Principle as to the best means of Doubling the Carrying Capacity of the Waterway.

It was considered that the enlargement pure and simple of the canal was incontestably the best solution:—Because an enlargement could speedily be made of the same width as the existing sidings, so as to provide passing-places in the canal from end to end; a disposition which would realize almost the same conditions of passage as could be afforded by two separate canals, whilst at the same time—owing to the larger sectional area of a widened canal—vessels would be able to accomplish their transit with more speed and safety than by means of two separate channels each having the same area as the existing canal. Because, eventually, by increasing the width threefold in the straight reaches and fourfold in the curves, steamers in motion would be able to pass each other in safety, at a reduced speed, at any part of the canal; and, finally, because the cost and maintenance of a double canal of the same dimensions as the existing waterway would be very much greater than the cost and maintenance of a single canal of the dimensions proposed by the Engineer-in-chief.

2. Dimensions of the proposed enlarged Canal.

Difference of opinion on the relative merits of Widths and Depths of an enlarged Canal.—Long discussions took place at the final sittings of the Sub-Commission as to the relative values of widths as compared with depths of channel, owing to the circumstance that, according to the estimates of Mr. Lemasson, the adoption of a depth of 9 metres instead of 8 metres would involve an extra outlay of £1,500,000, unless the bottom widths were considerably reduced in order to meet the cost of the extra depth proposed.

With regard to the merits of this important question there was a marked difference of opinion; certain members of the Sub-Commission attaching the utmost importance to a notable increase of depth, even at the expense of a diminished width, and other members holding to the opinion that any additional depth was unnecessary. The two English delegates and Mr. James Laing, who took a leading part in the discussion on this important matter, expressed their opinions strongly in the former sense, and endeavoured, but with only partial success, to convince their dissenting colleagues of the supreme importance of affording a free passage to vessels of a draught of 27 feet with 2½ feet under the keel; whilst, on the contrary, certain other members of the Commission contended that

there was no necessity to provide vessels with a greater draught than 7½ metres (24 feet 6 inches) with ½ a metre under the keel.[1]

Finally, in order to come to a unanimous vote on the question, it was decided without a dissentient voice that the project and estimate for the enlargement of the canal should (whilst retaining the widths recommended by Mr. Lemasson) include a final deepening to the depth of 9 metres (29 feet 6 inches) below the level of low water of ordinary spring tides; but at the same time the Sub-Commission agreed, as a compromise, to recommend that the programme of the successive stages of the execution of the works should be regulated with the view of realising a depth of 8·50 metres (28 feet) in the first instance; the complement of 0·50 metre (1 foot 7 inches) being comprised in the last stage of the enterprise.

Estimated Cost of the Enlargement Works.—The estimated cost of the enlargement works recommended by the Consultative Commission and sanctioned by the directors was as follows:—

		Estimated Cost.
		£
First phase—Excavation and dredging	21,064,000 cubic metres	2,449,600
Second " " " "	43,569,000 "	5,190,200
Third " " " "	4,992,000 "	660,200
Totals . . .	69,625,000	8,300,000
Deduct sale of plant		182,000
Total		£8,118,000

The excavation and dredging of 69,625,000 cubic metres comprised 310,000 cubic metres of gypsum in the Port Said section, and 743,279 cubic metres of rock in the Suez section. The total expense also includes a sum of £314,000 for stone revetments.

Reconstitution of the Consultative Commission of 1884–85.—The enlargement works were commenced in 1887, when all the members of the Sub-Commission who had visited Egypt in 1884 were invited by the Board of Directors to serve as members of a new Consultative Commission ("Commission Consultative International des Travaux"), whose duty it should be to meet annually

[1] The Author strongly advocated the adoption of a depth of 9·50 metres (31 feet) from end to end of the canal, so as to allow steamers drawing from 8·50 metres (28 feet) to 9 metres (29 feet 6 inches) to pass freely through the improved waterway with a sufficient depth under the keel, on the completion of each phase of the proposed widening.

in Paris to discuss all important matters connected with the improvement of the canal.

The ex-Sub-Commission having (with the exception of Mr. Tillier, appointed chief of the transport service of the canal, and of Mr. Dirks, removed by death) accepted this invitation, the first meeting of the newly-constituted Commission, reinforced by the addition of six new members,[1] was held in Paris on the 4th and 5th of November, 1887, and has so continued to meet every autumn up to this time. The British representatives on the new Consultative Commission of 1887 are Sir John Wolfe Barry, K.C.B., and the Author, the former having been appointed by the British Government in 1892, on the death of Sir John Coode, and the latter in 1884, as already stated. It should also here be remarked (1) that, after a residence of nearly thirty years in Egypt, Mr. Lemasson was basely assassinated at Ismailia in 1894 by a discontented workman during a prolonged strike, and that since this deplorable and universally regretted event, his functions have been admirably performed by Mr. Quellennec, a distinguished engineer of the roads and bridges of France; (2) that Voisin Bey, on his appointment in 1893 as a director of the company, resigned, to the great regret of all his colleagues, his post as President of the International Consultative Commission, being succeeded in the latter capacity by Mr. Laroche, inspector-general of roads and bridges; (3) that the vacancies by death since the reconstitution of the Sub-Commission of 1884-85 of Admiral Jurien de la Gravière and Messrs. Pascal and Larousse, and the resignation of Voisin Bey, have been filled up by Admiral Lefont and Messrs. Guérard, Oppermann, and Pérouse (Appendix No. III.).

Changes in the Chairmanship of the Canal since 1893.—It should further be recorded that, on the demise in 1894 of Count Ferdinand de Lesseps, Mr. Jules Guichard was elected President of the Suez Canal Company, to be succeeded in his turn, owing to his premature death in 1896, by Prince Auguste d'Arenberg, the present able and highly esteemed President of the company.

Execution of the First Stage of the Enlargement Works.—The first phase of the enlargement was completed in December 1898 from a width of 22 metres to 37 metres (121 feet 4 inches), and from a depth of 8 metres (26 feet 3 inches) to 8½ metres (27 feet 10 inches), or 12 years from the commencement of the work; a much longer time than was originally specified, owing to financial

[1] Admiral Jurien de la Gravière and Messrs. Laroche, Larousse and Pascal representing France; Mr. Saavedra, Spain; and Captain Alexéieff, Russia

considerations and to the circumstance that the increased capacity of the canal for traffic, owing to its illumination by electricity, rendered it unadvisable, in the opinion of the Directors, to carry on the work as expeditiously as was at first intended.

The execution of the work comprised in the first stage, the details of which have already been described, calls for no special remark, neither, for want of space, can anything be said here concerning the comparatively unimportant modifications which were recommended by the Consultative Commission during the progress of the work. It should be recorded, however, (1) that the type of revetments recommended by the Consultative Commission of 1885 have, as a rule, been adopted in practice—the precise locality and details of the work in connection with the nature of the ground to be dealt with being left to the discretion and appreciation of the Engineers-in-chief; (2) that the leisurely manner in which the improvements contemplated by the Directors in 1885 have been carried out up to this time, has had the benéficial effect of reducing to a minimum the many inconveniences to traffic which are inseparable from the execution of extensive dredging and revetting operations in a crowded channel; and (3) that it is a matter of congratulation, thanks to the skill and forethought of the engineers of the company, that the actual excavation and dredging (21,638,700 cubic metres) removed during the first stage of the work has only been 2½ per cent. in excess of the quantity originally estimated.

Increased Draught of Vessels since 1890.—The advantage to trade by increasing the limit of the draught of steamers on the 15th April, 1890, from 7·50 metres (24 feet 6 inches) to 7·80 metres (25 feet 7 inches) is proved by the fact that, whilst in 1891 the percentage of vessels passing through the canal drawing from 24 feet 6 inches to 25 feet 7 inches was only 3·20 per cent. compared with the total number, the proportion in 1897 amounted to 13·1 per cent. (391 vessels in 2,986).

Second Stage of Enlargement.—For many years past the dimensions, especially the beam of steamers, have been greatly augmented. Thus, since 1893, a large number of cargo vessels, with lengths of 460 feet to over 520 feet and beams from 60 to 70 feet, have passed through the canal for the first time, whereas in 1885 the maximum length and beam of trading vessels frequenting the canal did not exceed 460 feet and 48 feet respectively.

New Sidings.—In view of this remarkable augmentation of the dimensions of trading ships in so short a time, the Directors, in 1897, decided on the creation of nine new sidings, 15 metres

(49 feet) wide, and 750 metres (2,460 feet) in length, in order to facilitate the passage through the canal of steamers of the greatest beam. These new sidings, seven of which are established between Port Said and Sheikh Ennedek, 46 miles from the former place, and two between the Bitter Lakes and Suez, are now completed to their full width and give great satisfaction to the navigation.

Further Widening and Deepening of the Canal.—A constantly growing traffic will probably at no distant period demand a reconsideration of the question of practically carrying out the recommendations of the Consultative Commission of 1884–85 with regard to the further widening of the canal, after taking into account the course of proceeding suggested by the light of experience.

Meanwhile, it seems to the Author highly desirable, in the interest of commerce, that a sufficient depth should be provided, as soon as practicable, for vessels of a draught of 8·50 metres (27 feet 10 inches), instead of limiting it to 7·80 metres (25 feet 7 inches) as at present; and, further, that eventually the canal and its sea approaches should be deepened to 10 metres (32 feet 9 inches), so as to give an available depth of 9·50 metres, and thus not only to provide a receptacle for deposit ("chambre d'apports") ½ a metre deep throughout the canal, but also to permit vessels drawing up to 9 metres (29 feet 6 inches) to pass safely from sea to sea with a minimum of ½ a metre of water under the keel.[1]

Present and Prospective Depths at Port Said.—In October, 1894, the Consultative Commission decided on recommending the Directors of the Company to arrange for the maintenance, by means of dredging, of a channel 10 metres deep and 200 metres wide at the sea entrance to Port Said. Although this has not yet been attained, strenuous efforts have since been made, and are now being applied, notably by the provision of a very powerful marine bucket-and-hopper dredger, to establish the desired depth and width of channel at the Mediterranean entrance, as well as to continue the systematic dredging of the channel within the shelter of the west jetty, which has been in operation since 1886. In order to maintain a minimum depth of 9 metres

[1] The largest ocean steamers have now lengths of from 600 to 700 feet, beams of from 60 to 70 feet, and draughts when fully laden of from 27 to 31 feet. The Amsterdam Ship Canal and the Baltic Canal (from Kiel to the Elbe) have been recently deepened to nearly 30 feet. At Liverpool, New York, and Antwerp, the depth is now over 30 feet at low water; and at many other first-class ports channels equally deep either have been provided or are projected.

(29 feet 6 inches) at Port Said, 663,140 cubic metres were dredged between, and to seaward of, the jetties in 1898, and, in addition, 181,370 cubic metres of deposit were removed from the inner basins, exclusive of a cube of 565,800 cubic metres dredged from the canal itself between Port Said and Suez (Port Thewfik).

Actual and Prospective Depths in the Canal.—On the 1st January, 1899, there was an available depth of 9 metres (29 feet 6 inches) over an aggregate length of 90 kilometres, and by continuing to dredge down to 9·50 metres (31 feet) as at present practised, the engineers of the company hope by 1902 to obtain the latter depth throughout the whole length of the canal. It should here be explained that this contemplated depth of 9·50 metres in 1902 includes the provision of a receptacle for deposit ½ a metre deep over the entire bottom width of the canal from end to end.

Depth at Suez.—At the Suez entrance, at the present time, a vessel drawing 7·80 metres (the maximum draught allowed) has a depth of 1 metre under her keel at ordinary low water of spring tides, and a minimum of 40 centimetres under her keel at an extraordinary low tide.

Changes in the Contours of the Shore and Sea-Bed at Port Said (Fig. 5, Plate 2).—Regarding the changes that have taken place in the position of the shore line and the contour lines of soundings facing Port Said since 1859, there is only space to summarize the results of the latest investigations that have recently been made on this important subject.

These results are deduced from a chart of comparative contours in 1859, 1875, and 1898, prepared under the direction of Mr. Quellennec. Between 1859 and 1875 the construction of the West Jetty naturally caused a serious disturbance in the condition of the shore line and sea bottom at Port Said, and on this account no special reference need here be made to the abnormal advance of the contours adjacent to Port Said between these two dates. On the other hand, since 1875, the changes produced by the projection of the jetties having been regular in their action, the following remarks refer exclusively to the variations in the position of the shore and deep-water contour lines in 1875 and 1897.

Changes West of the West Jetty.—The shore line advanced seaward from 200 to 250 metres immediately adjacent to the jetty, but thence the shore contours of 1875 and 1897 approached each other as they trended westward, and finally met at a point about 4½ kilometres from the jetty. The 7-metre contour line of 1897 was almost identical with the 7-metre contour of 1875. The

8-metre contours of 1875 and 1897 frequently intersected to a distance of 3½ kilometres west of the jetty, but from that point to a further distance of 8 kilometres the advance of the 8-metre contour of 1897 averaged 500 metres.

Changes in the Face of the Canal Entrance.—Between 1875 and 1897 the stability of the 10-metre contour directly in face of the Canal over a width of 4 kilometres was remarkable. During this period, however, the advance of the 11-metre contour over the same limited width of 4 kilometres averaged 800 metres, whilst its maximum advance exceeded 1,200 metres. The sudden inflection of the 9-metre and 10-metre contours facing the entrance to the Canal was obviously due to the dredging operations in that locality.

Changes East of the West Jetty.—The shore line was eroded by the sea to the extent of from 200 to 300 metres for a distance of more than 5 kilometres from the jetty. The variations in the contour depths of from 4 to 9 metres in a region extending to a distance of 4 kilometres east from the jetty, were principally due to the deposit over a long period of sand and silt dredged from the Canal.

The facts (1) that, thanks to constant dredging, the position of the 10-metre contour over a distance of 2,000 metres to the west, and the same distance to the east of the entrance channel, was in effect the same as in 1875; and (2) that the dredging operations in the roadstead, and along the east side of the west jetty, have hitherto maintained an excellent channel, 9 metres in depth (notwithstanding the general advance of the 11-metre contour at the rate of 40 metres a year since 1875), encourages the belief that the maintenance of a channel of the desired depth of 10 metres can be assured at a reasonable cost, by means of an improved system of persistent dredging, unaided, for many years to come, by an extension of the West Jetty.

Subsidiary Works of Improvement.

The special works of improvement not included in the enlargement of the canal, recommended by the Consultative Commission in 1884–85, are as follows:—

1. Additional harbour accommodation at Port Said.
2. Extension of the fresh-water canal from Ismailia to Port Said
3. Plantations along the banks of the fresh-water canal.
4. Construction of a Tramway from Port Said to Ismailia in connection with the railway to Cairo and Suez.

5. Establishment of substantial mooring posts at frequent intervals along the whole length of the maritime canal.

These highly useful subsidiary works, of which only a bare mention can here be made, are now satisfactorily completed.

Gradual Increase of Traffic from the End of December, 1873, to the 31st December, 1898.

Increase of Traffic since 1873 in Quinquennial Periods.—The following Table, deduced from the "Comptes rendus" of the Company, shows the quinquennial increase of traffic through the canal, and also the quinquennial increase of the revenue from the 31st December, 1878, to the 31st December, 1898:—

Years.	Number of Vessels.	Net Tonnage.	Percentage of Quinquennial Increase of Tonnage.	Average Tonnage per Vessel.	Revenue exclusively from Taxes on Shipping.	Percentage of Quinquennial Increase of Revenue.
					£	
1873	1,173	1,367,767	..	1,170	324,430	..
1874–78	7,471	10,363,330	..	1,390	5,410,265	..
1879–83	12,735	20,308,201	96	1,600	9,071,886	67
1884–88	16,585	30,518,765	194	1,770	11,700,000	116
1889–93	17,921	37,743,145	263	2,000	14,038,254	169
1894–98	16,684	42,185,817	306	2,270	15,124,595	180
1898	3,503	9,238,603	..	2,640	3,306,290	..

An analysis of this Table shows (1) that the number of vessels passing through the canal in the quinquennial period 1894–98 was almost precisely the same as in each of the quinquennial periods 1889–93 and 1884–88; (2) that the increase of net tonnage in the four quinquennial periods ending the 31st December, 1898, as compared with the quinquennial 1874–78, was 96 per cent., 194 per cent., 263 per cent. and 306 per cent. respectively; and (3) that the increase of revenue from shipping only during the same four quinquennial periods was 67, 116, 169 and 180 per cent. respectively; (4) that the revenue derived from shipping in 1898, a record year, amounted to £3,306,290;[1] and (5) that comparing 1898 with 1873 the tonnage has increased sevenfold in 25 years. (*Fig. 6*, p. 182.)

[1] In 1898 the total revenue was £3,516,250, including revenue derived from the waterworks, the tramway, the sale of land and the tax of 10 francs per head on 219,554 passengers.

The result of this investigation is instructive, and seems to indicate clearly that during the next decade the execution of still further important works of enlargement will be found necessary in order to keep pace with the legitimate requirements of a constantly increasing trade.

Fig. 6.

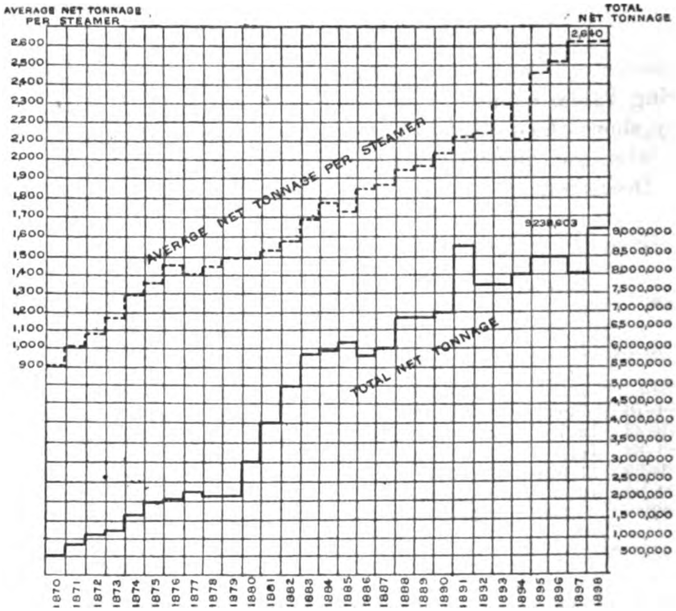

DIAGRAM SHOWING THE GROWTH OF TRAFFIC AND THE INCREASED TONNAGE CAPACITY OF STEAMERS FROM 1870 TO 1898.

Distribution of Profits.—On the 31st December, 1898, the balance in favour of the company for the year was 46,618,000 francs, (£1,864,700). The apportionment of that sum was as follows:—

	Per Cent.
Shareholders	71
Egyptian Government	15
Founders	10
Directors	2
Employees	2

Trade of different Nationalities compared.—In connection with the traffic of last year, attention should be drawn to the following Table, giving the relative net tonnage of 3,503 vessels belonging

to twenty different nationalities making use of the canal in the year ending the 31st December, 1898.

Nationality.	Number of Vessels.	Net Tonnage.	Percentage of Tonnage.
British	2,295	6,297,743	66
German	356	969,598	11
French	221	571,517	6
Dutch	193	381,866	4
Austrian	85	213,020	2¼
Japanese	46	183,325	2½
Russian	48	153,191	2
Spanish	49	149,306	2
Italian	74	137,294	1½
Eleven other nationalities	136	181,743	2¼
	3,503	9,238,603	100½

With regard to British trade, it may be pointed out that whereas in 1892 the tonnage was 75 per cent. of the total traffic of the canal, it had fallen to 66 per cent. in 1898; on the other hand, the British tonnage of last year (6,297,743 tons) exceeded the total tonnage of the canal (5,903,025 tons) in 1887.

Electric Light.—It has already been observed that the introduction of electric light has had the effect of virtually doubling the carrying capacity of the canal; but before concluding this Paper something more should be said, owing to the great importance of the subject, on the practical application of the system of lighting now in vogue for effecting the night navigation of the canal with ease, economy, and safety.

At the close of 1885 it was decided to make use of electric light in such a manner as to ensure a safe passage by night through the canal, the Company hoping in this way to diminish the traffic by day and thus to render the navigation less difficult till the full enlargement of the waterway was accomplished. A system of leading marks, supplemented by Pintsch light buoys, was therefore established along the banks of the canal in order that the navigable channel might be clearly indicated.

It was soon recognised, however, that this system would be insufficient to ensure perfect safety, and thereupon it was decided that every vessel in motion during the night should itself be provided with the necessary apparatus to illuminate her own passage through the canal. Accordingly, it was arranged that every vessel passing by night should carry four lights, to one of which should be applied a powerful reflector, capable of spreading

light 4,000 feet ahead of the vessel. Of the other three lights, one should be placed astern and one on each side of the ship.

The Mangin reflector is generally used. Men-of-war and large postal steamers carry their own apparatus. Smaller vessels generally use a portable apparatus, which they hire on entering the canal, returning it on leaving. The apparatus consists of a reflector, a dynamo and a motor. Besides the "Mangin," several other kinds of reflectors are used with more or less efficiency.

The system of navigating by night as at present practised leaves nothing to be desired, inasmuch as the narrowness of the canal compels the adoption of the single line or block system in the transit of vessels from sea to sea. Some other mode of lighting would, however, require to be arranged to ensure the safe passing of vessels under way by night if the canal should ever be enlarged to the full dimensions contemplated by the Directors in 1885; as the traffic managers of the canal are convinced by experience of the impracticability of two vessels in motion, carrying electric projectors, passing each other in contrary directions without danger, owing to the dazzling effects of the travelling lights on the vision of the pilots.[1]

The first vessel that effected the through passage by night was the P. and O. steamer "Carthage" in 1886, the time of transit being 18 hours. In 1888, 46 per cent. of the total shipping took advantage of the permission to steam through the canal day and night as compared with 71 per cent. in 1889; the result being that for the whole navigation, the average passage for all vessels was reduced from 30 hours 45 minutes in 1888 to 26 hours 44 minutes in 1889. In 1898, 94 per cent. of the total shipping made part of their passage by the aid of the electric light, the average duration of transit being 17 hours 22 minutes, and the minimum duration only 16 hours 36 minutes, whereas the average time taken by steamers navigating by day was 28 hours 20 minutes.

These figures prove that the passage of the Suez Canal by night has become almost universal, to the immense relief of the navigation.

The Paper is accompanied by diagrams, from which Plates 2 and 3 and the Figure in the text have been prepared.

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[1] At the present time, steamers passing the Canal by night are subject to the rules embodied in the "Regulations for Navigation in the Suez Canal" issued 1 January, 1899. (Appendix No. IV.)

APPENDIXES.

APPENDIX I.

The first International Consultative Commission was constituted in October, 1855. Austria was represented by Mr. de Negrelli, Inspector-General of Railways; Italy by Mr. de Paléocapa, Minister of Public Works; Spain by Mr. Montesino, Director of Public Works at Madrid; Holland by Mr. Conrad, Director-General of the Waterstaat; Prussia by Mr. Lentzé, Engineer-in-Chief of the Vistula; France by Mr. Renaud, Inspector-General of Roads and Bridges, Admirals Rigault de Genouilly and Jaurès; and England by Messrs. Rendel, Maclean and Manby, Civil Engineers, and Captain Harris, who had made seventy voyages in the Red Sea.

Messrs. Linant-Bey and Mougel-Bey, engineers of the Viceroy, met the Commission in Paris and returned thither in November with Messrs. Conrad, Maclean, de Negrelli, Reynaud and Lissou, a sub-committee of five members, who had been deputed by their colleagues to make a careful study of the ground between the two seas in order to convince themselves of the entire feasibility of the scheme proposed by Mr. Ferdinand de Lesseps.

APPENDIX II.

The "International Consultative Commission of 1884–85" was composed as follows (copied from the official statement published in the "Revue-Gazette Maritime et Commerciale" of the 30th May, 1884):—

Membres représentant la France.

Messrs. Lefébure de Fourcy, inspecteur-général des ponts et chaussées (Président).
Le Vice-Amiral Jurien de la Gravière, membre de l'Institut.
Pascal, inspecteur-général des ponts et chaussées.
Voisin-Bey, inspecteur-général des ponts et chaussées (Rapporteur).
Laroche, ingénieur-en-chef des ponts et chaussées (Rapporteur-adjoint).
Larousse, ingénieur hydrographe.
Tillier, lieutenant de vaisseau, capitaine des Messageries Maritimes.
Dumont, officier de la Compagnie nationale de Navigation de Marseille.

Membres représentant la Grande-Bretagne.

Major-General Sir Andrew Clarke, du Génie Royal Britannique (Vice-Président).
Sir Charles Hartley, ingénieur-en-chef de la Commission Européenne du Danube, et membre de l'Institut des Ingénieurs civils d'Angleterre.
Sir John Coode, vice-président de l'Institut des Ingénieurs civils d'Angleterre.
Captain Chitty, de la Marine Royale Britannique.

THOMAS SUTHERLAND, président de la Compagnie de Navigation a vapeur Péninsulaire et Orientale.

JAMES LAING, président du Comité des Armateurs de steamers engagés dans le commerce de l'Orient.

WILLIAM MACKINNON, président de la Compagnie de Navigation "British India."

ROBERT ALEXANDER, Armateur.

MEMBRES REPRÉSENTANT LES AUTRES PUISSANCES MARITIMES ÉTRANGÈRES.

Allemagne.—M. PESCHECK, inspecteur du service des voies fluviales en Prusse, attaché à l'Ambassade d'Allemagne à Paris.

Autriche-Hongrie.—M. BLASIUS CRILLANOVICH, capitaine du Lloyd austro-hongrois.

Espagne.—EDUARDO SAAVEDRA, ingénieur-en-chef de prémière classe des ponts, canaux et chaussées, membre du Comité supérieur facultatif de la Marine à Madrid.

Italie.—Le Commandeur EDOUARD GIOIA, ingénieur-en-chef, Rome.

Pays-Bas.—M. DIRKS, ingénieur-en-chef du Waterstaat (Vice-Président).

Russie.—ALEXÉIEFF, capitaine de frégate, attaché à l'Ambassade de Russie à Paris.

M. VIEUSSA (France), chef du service des travaux de la Compagnie à Paris, Secrétaire.

At the final meetings of the Consultative Commission at Paris on the 9th and 11th February, 1885, the following gentlemen connected with the Company assisted at the meetings:—

FERDINAND DE LESSEPS, Président-Directeur de la Compagnie.

E. DAUPRAT, CHARLES-A. DE LESSEPS, MOURETTE, Vice-Présidents.

V. DELAMALLE, MOTET BEY, E.-J. STANDEN, BARON J. DE LESSEPS, Administrateurs, Membres du Comité de Direction.

ANSLYN, LE BARON A. DE CATERS, A. DE CLERCQ, J. GUICHARD, J. HERBETTE, C.-J. MONK, A. PEGHOUX, le Colonel Sir JOHN STOKES, Sir C. RIVERS WILSON, DE MONDÉSIR, Administrateurs; (Directors).

MARIUS FONTANE, Secrétaire-général de la Compagnie.

LEMASSON, Ingénieur, chef du service de l'entretien en Égypte.

GRINDA.

LE CAPITAINE JACKSON, de la Marine Royale anglaise, de l'État-Major du Major-général Sir Andrew Clarke.

V. DAUZATS, chef des travaux à Paris.

P. A. SAVOUILLAN, Chef des études de la Compagnie à Paris.

APPENDIX III.

List of Members of the International Consultative Commission as constituted in 1899.

France—
Mr. Laroche (President).
Admiral Lafont.
Mr. Guérard.
Mr. Oppermann.
Mr. Perouse.

Great Britain—
Sir John Wolfe Barry.
Sir Charles A. Hartley.

Germany—
Mr. Peschpeck.

Austria-Hungary—
Captain Crillanovich.

Spain—
Mr. Saavedra.

Italy—
Mr. Gioia.

Holland—
Mr. Conrad.

Russia—
Captain Shein.

Secretary, Mr. Vieussa.

Engineer-in-Chief of the Suez Canal Company, Mr. Quellennec, C.M.G.

Chief Traffic Manager, Captain Tillier, C.M.G

APPENDIX IV.

Regulations for the Navigation of the Suez Maritime Canal.

Issued January, 1899.

Art. 1.

On receiving a copy of the present regulations captains of ships shall bind themselves to abide by and conform themselves to these rules in all points, to obey all signals therein mentioned and satisfy any requisition made in view of the execution of these regulations.

Art. 2.

The transit through the Suez Canal is open to ships of all nationalities, provided that their draught of water does not exceed 7 metres 80 centimetres (25 feet 7 inches English), and that they conform to the following conditions:—

Sailing vessels above 50 tons gross are bound to be towed through.

Steam vessels may pass through the Canal by means of their own steam power or be towed subject to the conditions hereinafter notified.

Of course the towage of steamers through the Canal is not compulsory on the Company; it will only be performed in so far as they have unengaged tugboats.

Art. 3.

The maximum speed of all ships passing through the Canal is fixed at 10 kilometres, equal to 5½ nautical miles per hour.

ART. 4.

Every vessel measuring more than 100 tons gross must take on board either for entering or clearing the ports of Port Said and Port Thewfik, or for passing through the Canal, a pilot of the Company, who will furnish all particulars as to the course to be steered.

The captain is held responsible for all groundings and accidents of whatsoever kind, resulting from the management and manœuvring of his ship by day or by night.

Pilots place at the disposal of captains of vessels their experience and practical knowledge of the Canal; but as they cannot be specially acquainted with the defects or peculiarities of each steamer and her machinery, in stopping, steering, etc., the responsibility as regards the management of the ship devolves solely upon the captain.

ART. 5.

When a ship intending to proceed through the Canal shall have dropped anchor either at Port Said or Port Thewfik, at the berth appointed by the harbour master, the captain must enter his ship at the Transit Office and pay all dues for passage, and when there is occasion, for pilotage,[1] towage and berthing; a receipt for the same shall be delivered to him, which will serve as a voucher whenever required.

The following written information must be handed in by the captain:—

Name and nationality of the ship, to be identified by exhibiting the ship's papers respective thereto.

Name of the captain.

Names of the owners and charterers.

Port of sailing.

Port of destination.

Draught of water.

Number of passengers as shown by the passage list.

Statement of crew as shown by the muster roll and its schedules. (Sailors occasionally taken on board of vessels passing through the Suez Canal are not considered as forming part of the crew and are taxed in conformity with paragraph 6 of art. 11 of the present regulations.)

Capacity of the ship according to the legal measurement ascertained by producing the special Canal certificate, or the ship's official papers established in conformity with the Rules of the International Tonnage Commission, assembled at Constantinople, in 1873.

ART. 6.

The Company determine the hour of departure of each ship, and all subsequent stopping and re-starting, as well as all other movements of the ship in such manner as to give full security for the navigation as well as to ensure as much as possible the rapid passage of mail steamers.

Therefore no ship can demand as a right an immediate passage through the Canal, neither will any claim be admitted in connection with any delay originating from the foregoing causes.

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[1] For pilotage dues into and out of Port Said harbour, see art 13.

Since the 1st of July, 1884, and until further orders, the pilotage dues for the journey through the Canal are not charged.

Unless otherwise ordered, ships engaged upon mail service, under the conditions specified in the next paragraph, happening to be at anchor or stopped in Lake Timsah or at the South Light or North Light berths, at the same time with other ships, whether ships of war or merchant ships, are authorized to pass such other ships and to continue their journey first, in their respective order of arrival in the Lakes.

Mail steamers, viz., steamers performing a regular mail service under contract with a government, at fixed dates appointed in advance and having been duly vouched for as such, shall carry at the foremast head by day a blue signal with the letter P cut out in blank in the centre, and by night a white light.

Art. 7.

All ships ready to enter the Canal must have their yards braced forward, their jib-booms run in and their boats swinging in board. In addition to their two bow anchors, they must carry at the stern ready for letting go at the request of the pilot a strong kedge with a stout hawser bent on sufficient to hold the ship.

Art. 8.

§ 1. Every ship must, during her passage through the Canal, have either in tow or ready to float a fitted-out boat carrying a hawser in readiness to be run out at once and made fast to one of the mooring posts on either side of the Canal.

§ 2. The captain must set a watch both by day and night; the men to be in readiness to ease away or cut hawsers, as may be required.

All ships, whether made fast in a siding, or moored at any point, or aground in the Canal, shall ease their hawsers in order to give free passage to tugs, steam launches, hopper-barges and any other craft of a light draught, that may have to pass them.

§ 3. All steamers, tugs included, must blow their whistles when approaching the curves of the Canal, also when approaching in either direction boats or lighters, dredgers or any craft afloat. They must stop when the channel is not clear and pass at a reduced speed all sidings, stone or earth-work yards; they must also slacken speed and have their two bow anchors ready for letting go when passing vessels made fast or under way, hopper-barges, dredgers or any other craft.

§ 4. Whenever a collision appears probable, no ship must hesitate to run aground and thus avoid the collision. The expenses consequent upon grounding under these circumstances shall be defrayed by the ship in fault.

§ 5. Ships proceeding in the same direction are not allowed to pass each other under way in the Canal.

In the case of a ship being allowed to pass another one ahead of her, she must conform with the Company's directions to that effect.

§ 6. Navigation of sailing craft of every description at night is entirely forbidden.

§ 7. Steamers intending to go through the Canal at night must first satisfy the agents of the Company in Port Said, or Port Thewfik, that they are provided:

1. With an electric search-light or search-lights showing the channel 1,200 metres ahead and so constructed as to admit of rapid splitting up of the beam of rays into two separate segments with a dark sector in the middle.

2. With electric lights powerful enough to light up a circular area of about 200 metres diameter around the ship.

The agents of the Company will decide whether the apparatus fulfil the requirements of the regulations so that ships provided with them may, without inconvenience, be authorized to navigate the Canal at night.

Night transit may, however, be suspended in case of failure or want of power in the lights.

§ 8. While navigating by night-time, ships must carry their usual lights and have a man on the look-out forward.

Whenever a vessel navigating by night has made fast, whether in a siding or in the Canal, she must thereupon at once extinguish her search-light or search-lights, and lights above stated, as well as her course lights.

All ships navigating at night in the Large Bitter Lakes between the North and South Lights must extinguish their search-light or search-lights.

Any ship coming into Port Said at night from the South must extinguish her search-light or search-lights when making the curve from the Canal into the harbour.

§ 9. Whenever a ship navigating at night is accidentally stopped on her way, her white light astern must at once be replaced by a red light. In case other vessels are following her she must, at the same time, sound her steam-whistle four or five times in close succession, repeating this at a few moments' interval until the ship following her repeats this signal, which shall be taken as an order to slacken speed at once with a view to stopping, if need be.

§ 10. Whenever a ship makes fast, enters a siding, or gets aground, the captain must give immediate notice thereof by means of the signals specified in the appendix to these regulations.

§ 11. Navigation by night-time by steamers unprovided with electric light is only authorized under exceptional circumstances, the captain accepting entire responsibility in writing for any delay, mishap and damages that may happen to his own ship, as well as for any similar accidents he may cause to other ships in transit or to the Company's craft and plant happening to be in the Canal. Ships navigating under these conditions remain subject to all other rules regarding night transit.

Art. 9.

In the event of grounding, the agents of the Company alone shall have the right to direct all operations by which a vessel is to be floated off again, to unload and tow the vessel as may be necessary (by means of the plant, and stock which the Company has at hand), at the expense of the vessel, unless it be regularly proved that there was an insufficient depth of water in the Canal, or that erroneous direction by the pilot had caused the grounding.

The aforesaid costs of floating, towing, discharging and reloading, etc., must be paid conformably with a statement or estimate drawn up by the Company, before the departure of the ship from Port Said or Port Thewfik.[1]

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[1] From the 1st October, 1883, and until further orders, whenever a ship going through the Canal happens, except in the roads and ports, to ground or stop in consequence of an accident independent of collision, the Company, in order to remove the obstruction in the fairway with all possible speed, and to hasten the restarting of the grounded or stopped ship, will not claim from the captains, the consignees, or the shipowners, the reimbursement of whatsoever expenses incurred in refloating the ship, and, if deemed necessary, for towing her as far as the next siding. If from such siding the ship continues her journey in

All manœuvres with the object of helping grounded vessels to get off are formally prohibited to other ships in transit.

ART. 10.

The following prohibitions are hereby notified:

1. The overloading of the deck, before entering the Canal, with coals or other merchandise which might alter the general stability of the vessels or would interfere with navigation;

2. The anchoring of a ship in the Canal except through unavoidable circumstances, and then only with the consent of the pilot;

3. Throwing overboard in the ports and during the journey from sea to sea and at any point whatever of such journey, earth, ashes, cinders or material of any kind;

4. Picking up, without the direct intervention of the Company's agents, any thing that may have fallen into the Canal.

Should any material of whatever kind fall overboard, the circumstances are to be immediately made known to the pilot, who is instructed to transmit such information to the Company's agent at the nearest station.

The recovery of all articles dropped into the Canal, in whatever way such salvage is effected, shall be carried out at the expense of the captain to whom such articles will be restored against reimbursement of the said expense;

5. It is expressly forbidden, and on penalty of legal proceedings, to masters of ships while in the Canal or in the ports or sidings thereunto appertaining, to allow any guns to be fired from on board their ships;

6. They are forbidden to sound their steam-whistle in the ports of the Canal, except as an alarm signal in case of serious danger;

7. Burial in the banks of the Canal is forbidden.

ART. 11.

1. The net tonnage resulting from the system of measurement laid down by the International Commission of Constantinople, and inscribed on the special certificates issued by the competent authorities or on the ship's official papers, is the basis for levying the special navigation due, which is at present 9 francs.

In levying the dues, any alteration of net tonnage subsequent to the delivery of the above-mentioned certificate or papers shall be taken into account;

2. The Canal authorities may ascertain whether cargo or passengers are carried in any spaces which, as shown by the certificate of tonnage, have not been included in the gross measurements, or which were allowed as deductions for

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tow, she must pay towage charges according to rates annexed to the present regulations.

It is moreover well understood that ships will have to bear all expenses incurred for the necessary repairs or putting into condition with a view to remedy such damages as might interfere with their restarting, whatever be the time at which these damages may have occurred, and that the said ships will remain responsible for the damages which may be the consequence of their grounding.

The Company will continue to perform the work of refloating the grounded ships under the supervision of their officers exclusively, and will use first the means available on board, and afterwards or simultaneously, the machinery or appliances belonging to the Company.

the accommodation of the crew after measurement, or which, being within the engine, boiler or bunker space, form no part of the net tonnage shown on the certificate;

And generally may verify whether all the spaces which ought to be included in the tonnage are entered on the certificate and are exactly determined thereon.

3. Every vessel not provided with a special certificate or official papers giving the net tonnage laid down by the Constantinople Commission shall be measured by the Company's agents in conformity with the Constantinople rules, and shall pay her dues according to such measurement, until she produces a special certificate from the authorities of her own country.

4. Until further orders, ships in ballast will be allowed a reduction of 2 francs 50 centimes per ton on the tariff for transit.

5. Any ship carrying mails or passengers, or having in her holds coals or other merchandise in whatever quantity, is not considered as being in ballast.

6. The charge of ten (10) francs per passenger above twelve years of age or of five (5) francs per passenger from 3 to 12 years old, as well as the transit dues, must be prepaid on entering the Canal at Port Said or Port Thewfik.

7. The berthing or anchorage dues at Port Said, Ismailia and opposite the Company's embankment at Port Thewfik, are fixed at 0 franc 02 centime per day per ton, after a stay of twenty-four (24) hours at the berth assigned to the ship by harbour master and whatever be the duration of her stay. These dues will be collected every ten days.

8. Claims for errors in the declaration of tonnage or in the levying of the dues must be sent in within a month after the ship's passage through the Canal. After this delay, rectifications will not be admitted; no erroneous application of the tariff can ever be brought forward as a precedent against the Company.

ART. 12.

§ 1. In the case of ships either towed or convoyed by the Company's tugs no other division than that of one half of the length of the Canal shall be allowed; from Ismailia to Port Said being considered one half on one side and from Ismailia to Port Thewfik the other half, on the other side.

The charges for towage in the Canal by the Company's tug service are fixed as follows:—

For sailing vessels measuring 400 tons and under, 1,200 francs; for sailing vessels measuring above 400 tons, 1,200 francs for the first 400 tons and 2 francs 50 centimes for every surplus ton.

For steamers measuring above 400 tons, 2 francs per ton, without any distinction, upon their whole tonnage, but on the condition that they use their propelling power or keep it in readiness for assisting the tug.

Steamers measuring under 400 tons, also steamers not intending to give the assistance of their propelling power, will pay the same as sailing vessels.

For the towing of monitors, loaded or empty lighters, vessels not requiring the services of a first class tug, and all floating craft of any exceptional description, arrangements by contract to be made by private agreement.

It is hereby provided that when a tug shall only have accompanied or towed a vessel one half the length of the Canal, 600 francs shall be levied for the return trip of a first class, and 400 francs for a second class tug, and one half only of the total towage or tender dues shall be charged.

All ships towed must furnish their own warps.

§ 2. The charges for towage in the roads by the Company's tug service to ships applying for tugs, are fixed at 0 franc 25 centimes per ton of net tonnage at

Port Said for the distance between the inner docks and the end of the jetties and conversely; at Port Thewfik the distance between the docks and the roads and conversely, the minimum charge to be 50 francs.

For towage to a greater distance, the amount shall be settled by private agreement.

§ 3. When a ship shall require a tug to act as a tender the charge for such services will be 1,200 francs a day, if a tug of the first class be employed, and 800 francs a day for a tug of the second class. In the event of stoppage, the tug will render assistance in getting the vessel under way, each time that it may be necessary. If the vessel is towed by the tender any distance exceeding that of one station from another, the charge for towage may be demanded in lieu of the tariff fixed for acting as a tender.

§ 4. In all other cases, tug hire will be invoiced according to tariff rates annexed to the present regulations.

§ 5. Shipowners are authorized to have their vessels towed and accompanied by their own steam-tugs, all responsibility connected with such acts devolving upon themselves.

Such tugs are to be approved of by the Canal Company.

Ships towed or accompanied by tugs belonging to their owners will pay 0 franc 50 centimes (fifty centimes) per ton as towage dues.

Such tugs, whenever they shall tow or accompany vessels belonging to their own proper owners, will be free of any tax whatever.

Whenever they go through the Canal for the purpose of meeting vessels of their owners which they are entitled to tow or accompany, or when returning to their usual berths after having towed or accompanied them through, said tugs shall not be submitted to payment of the special navigation dues, but they must take a pilot on board.

Any transport of goods or passengers is prohibited to them; the fact of having on board passengers or goods would entail upon them the payment of all dues and charges to which ships in transit are subject.

Whenever the said tugs shall be used for towing or accompanying vessels not belonging to their own proper owners the same dues and charges shall be levied on them as on ships in transit.

Besides the special treatment specified by the present article, tugs belonging to private owners shall be subject to the strict observance of the present regulations concerning vessels berthing or in transit.

Art. 13.

Pilotage charges for entering Port Said harbour and leaving the same are fixed as follows for ships not going through the canal:—

Pilotage by daytime—
Steamers . . . . 25 francs.
Sailing ships . . . . 10 „

Pilotage by night-time, before sunrise and after sunset—
Steamers . . . . 50 francs.
Sailing ships . . . . 20 „

The payment of the pilotage charge for entering Port Said harbour and leaving the same is compulsory on every ship measuring 100 tons gross and upwards.

Whatever length of time ships may stay in the harbour of Port Said and whatever commercial operations they may transact there, total remission will be made of the pilotage charges for day-time entrance, or remission of half the charge for night-time entrance, if they decide to go through the canal.

The pilotage charge for entering or leaving Port Said harbour at night-time is fixed as follows for ships going through the canal:—

Steamers	25 francs.
Sailing ships	10 „

Twenty francs per day is levied for a pilot kept on board in case of berthing.

ART. 14.

Provisionally and until further orders, ships, barges, lighters and other craft, either coming in ballast or empty from Port Said under orders for Ismailia or returning from Ismailia to Port Said with cargoes of native produce; or bringing from Port Said to Ismailia cargoes bound to districts of Lower Egypt next to the Canal, and returning empty or in ballast from Ismailia to Port Said, shall be exempted, either outward or homeward bound whether they be empty or in ballast, from the special navigation dues, and shall only be subject to the payment of 2 francs 60 centimes per ton, for their passage when loaded outward or homeward bound.

Such toll is to be prepaid when said ships, barges, lighters or other craft, enter the Canal, in ballast or empty, to go and take cargo of native produce at Ismailia as well as when loaded.

As regards dues or charges other than the special navigation dues, said ships, barges, lighters or other craft, are bound to pay them in full.

ART. 15.

Charges of every description prescribed in these regulations must be paid in cash. Payments may be tendered either at the Company's Cashiers' Offices in Egypt, or at the Head Office in Paris, or in the hands of any of the agents of the Company appointed to that effect.

In the case of any amounts tendered otherwise than at the Company's Cashiers' Offices in the Isthmus, *receipts* are delivered to shipowners or consignees which the captain may hand as cash to the Company's agents in Egypt appointed to collect the dues.

In case of payments not being effected in time to admit of *receipts* being sent to captains, the Company will inform by telegraph their agents in Egypt of the amounts so paid. The cost of telegrams to be defrayed by the shipowners.

Whenever amounts thus paid in advance shall be insufficient for the discharge in full of all charges and incidental expenses due by ships, the balance must be paid in Egypt at the Company's Cashiers' Offices.

Paris, December 5th, 1898.

(Signed) PRINCE AUGUSTE D'ARENBERG,
President.

Discussion.

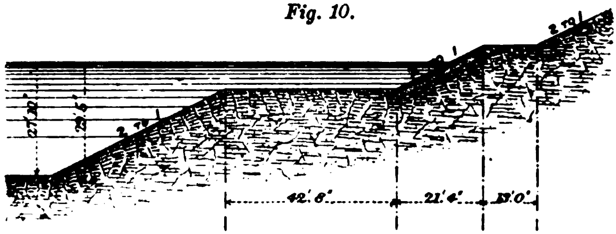
The PRESIDENT said that the Author was not in England, but Sir John Wolfe Barry had been kind enough to take charge of the Paper, and members would have the benefit of his explanation of the views which accompanied it. He felt sure the members would desire that a cordial vote of thanks should be conveyed to Sir Charles Hartley for his interesting communication. The President.

Sir JOHN WOLFE BARRY cordially shared in the regret which had been expressed by the President at the absence of Sir Charles Hartley, but he would do his best to represent him on the present occasion. There was no one of our fellow-countrymen now alive who was so well informed on the general subject of the Suez Canal as the Author, for he had been connected with it almost from its initiation. It was, he thought, a great source of congratulation to the Institution that Sir Charles should have been induced to put together the remarks which the members had had the pleasure of hearing. It was the only record in this country of many matters connected with the Suez Canal, and there was no one except Sir Charles Hartley who could have written it. He would like to refer to one or two matters mentioned in the text which might be interesting to the members. One of those was a subject of great importance to the whole kingdom, namely, the purchase of the shares by the British Government in 1875—a very remarkable episode in the history of the Suez Canal. In 1893 the Chancellor of the Exchequer stated in Parliament that the total estimated value of the Suez Canal shares, purchased in 1875 for four millions, was then £17,750,000, and that £3,805,000, out of the £4,000,000 which had been given for them, had been paid off by a sinking fund which he presumed was provided out of the fixed 5 per cent. interest on the shares, which was independent of profits on the working of the canal. The Author now stated that the market value of those shares was at the present date no less than £26,500,000. Politically in the management of the canal, and in the representation of this country on its board of direction, the result had been very far-reaching, quite irrespective of the wonderfully successful financial operation. Another matter was the questions which were put to experts by the Sub-Commission in Sir John Wolfe Barry.

Sir John Wolfe Barry.

1885 as to the adequacy of the proposed enlargement of the canal, with the view of allowing ships to pass each other under way. Those questions required answering now just as much as they did then. The subject of the widening of the canal for the above purpose had not yet become acute, but some day it would become so. All those questions were matters of great difficulty, and upon the answers given to them depended the engineering works which should be undertaken. As far as one could judge, the balance of opinion in 1885 seemed to be that a bottom width varying between 179 feet and 229 feet was generally considered sufficient, but it should not be forgotten that since that date the beam of vessels had considerably increased, and he would by no means be unprepared to hear from nautical gentlemen that the widths then considered adequate ought now to be proportionately augmented. He would like to draw attention to what the Author had said about the depth which in 1885 he and the other British representatives on

Fig. 10.



the Commission were most anxious should be adopted, viz., at least 9½ metres, or 31 feet. The British delegates were unfortunately in the minority, and could not carry their point; but the Author remained strongly of opinion that the depth of the canal should be 31 feet, and he only accepted 8½ metres, eventually to be increased to 9 metres, as a compromise between conflicting views at that time. He knew the Author entertained great hopes that the depth would be increased when the opportunity presented itself, even if the widening of the canal for the passage of two vessels under way were not simultaneously undertaken. He most cordially agreed with these views. He would like to call the attention of the members to a diagram (*Fig. 10*) which he had placed on the wall, showing the revetments last adopted by the engineers in charge of the canal for the preservation of the slopes. He could not say that any of the revetments, which from time to time had been tried, had proved to be perfect, as there was a great tendency for the toe of the revetments to be

more or less undermined by the waves due to the passing of vessels. The revetment shown in *Fig. 10* was the one now being carried out, and seemed to promise fairly good results. With regard to the dredging at Port Said harbour, everybody recognized the fact that it was a harbour which was entirely dependent upon dredging for its maintenance. Being situated as it was upon a long shelving shore, with a current continually carrying the deposits brought down from the Nile in a direction from west to east, any deep channel cut across the line of that current could only be maintained by persistent dredging. Looked at in connection with, and in proportion to, the enormous amount of traffic which passed through the canal, the amount of dredging was not very serious, though it was considerable, amounting to 700,000 cubic metres or 800,000 cubic metres a year. There was one little matter connected with the dredging which was somewhat interesting. As he had already said, the deposit from the Nile always trended from west to east, and consequently the shore on the west of the west jetty always had a tendency to increase very much more rapidly than that east of the harbour. The engineers of the Suez Canal had hit upon the idea that it would be advisable to attack those deposits by allowing them to pass through the western jetty, so as to be deposited on its east side, and that from that position they could more easily be dredged, as the dredgers doing the work would lie in a protected area, free from the effects of the sea. Although it might seem a strange thing to do, it had proved successful. In order to carry out this plan the great blocks of stone which formed the jetty were taken away from time to time to allow the sand, as it increased, to pass through the interstices and be deposited on the east side of the jetty. That had resulted in a considerable saving, and had proportionately diminished the dredging in the open sea. Before he sat down he should like, as a Member of the International Technical Commission, to which all works undertaken in connection with the canal were submitted for approval, to bear witness to the unvarying courtesy which was shown to Sir Charles Hartley and himself by all their colleagues, and to the careful consideration given by them to any views which they from time to time laid before them. He felt sure that it was the greatest wish of the Suez Canal Company and of the International Commission to maintain the high utility of the canal and to keep abreast of modern requirements as far as possible. Sir John Wolfe Barry.

Mr. L. F. VERNON-HARCOURT had placed a diagram (*Figs. 11, a* and *b*) on the wall, as he thought the members might be interested, Mr. Vernon-Harcourt.

Mr. Vernon-Harcourt. in seeing the tidal rises on the Suez Canal, and also the differences

Fig. 11b.

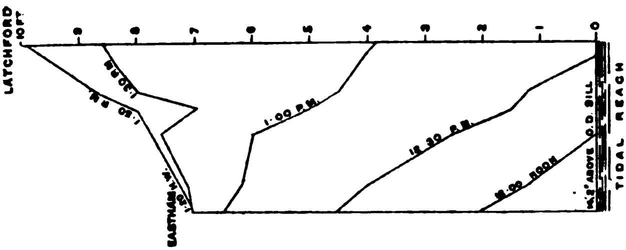
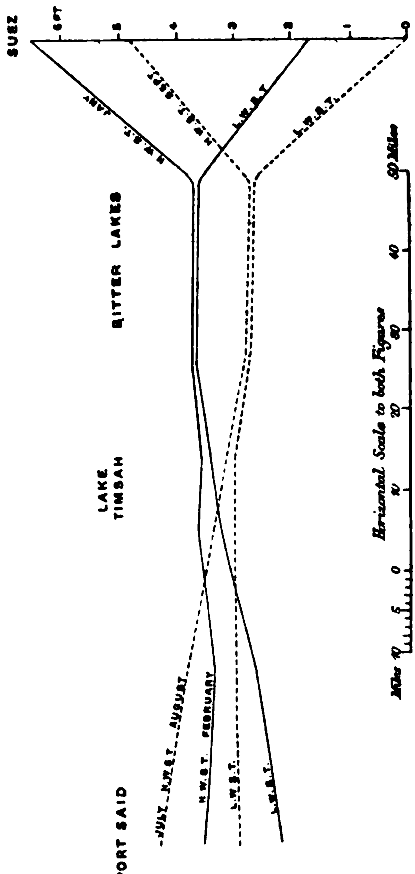


Fig. 11a.



in the tidal levels due to the wind at different periods of the

Mr. Vernon-Harcourt.

year, *Fig. 11a*. On the same diagram would also be seen the tidal rise towards high water during high spring tides in the Manchester Ship Canal above the ordinary level of the canal, 14 feet 2 inches above the Old Dock sill at Liverpool, *Fig. 11b*. That was not the present condition of the Manchester Ship Canal, but the condition that existed up to the time of the closing of the tidal openings in 1897. It represented one of the highest spring tides flowing up the canal; and the contrast in the tidal conditions of the tidal reach of the Manchester Ship Canal, 21 miles long, and of the Suez Canal was very remarkable. The maximum tidal rise at the Suez entrance of the Suez Canal was 4 feet 9½ inches in the usual tidal period, whereas on the Manchester Ship Canal at Eastham, the rise of 7 feet occurred during the last 1 hour 45 minutes of the flood tide, increasing to nearly 10 feet rise in less than 1 hour 20 minutes at the upper end of the tidal reach. With regard to the Suez Canal, the level of the tide varied according to the seasons on account of the wind. The maximum height in the Gulf of Suez, owing to the prevalent southerly winds, was in January and February, when the mean sea-level was 1 foot higher at Suez than in the Mediterranean Sea; while the maximum height in the Mediterranean, due to prevailing northerly winds, was in July, August, and September, when the mean sea-level at Suez was 1 foot 4 inches higher than the mean sea-level in the Mediterranean at Port Said. The dotted lines, *Fig. 11a*, showed the levels of high and low water of spring tides when the Mediterranean was the highest, and the full lines when the Gulf of Suez was the highest. From November to May, the flood tide predominated between Suez and the Bitter Lakes, and the maximum velocity with a strong south wind in January and February was 2·9 miles per hour; and the flow of water into the Bitter Lakes at that period in the six months, was as much as 667,230,000 cubic yards. The ebb tide, on the contrary, predominated in the northern part of the Canal between Lake Timsah and the Mediterranean, as clearly shown by the full lines, *Fig. 11a*, and was almost continuous in its flow in January and February, reaching a maximum velocity of 1·23 mile per hour; while the flow out of Lake Timsah in the six months amounted to 521,746,000 cubic yards. The reverse was the case from May to November, when the ebb tide predominated between the Bitter Lakes and Suez. The maximum velocity with a strong north wind was 2·7 miles per hour, the flow of water out of the Bitter Lakes being 528,000,000 cubic yards during this period. The flood tide, on the contrary, predominated, as was seen by the dotted lines, *Fig. 11a*,

Mr. Vernon-Harcourt. between the Mediterranean and Lake Timsah, and from July to September was almost continuous with a maximum velocity of from 1 to $1\frac{1}{3}$ mile per hour; while the flow into Lake Timsah was 753,120,000 cubic yards. It would be seen, therefore, that the flow into and out of those lakes depended on the season of the year. The ordinary spring tide rise at Suez was about 4 feet $9\frac{1}{2}$ inches and at Port Said on the Mediterranean 1 foot 4 inches. The tidal flow into the Manchester Ship Canal depended on the final portion of the rise of spring tides which alone could enter the Canal; whilst in the Suez Canal the tidal flow and ebb varied considerably in different parts of the Canal, and according to the prevalence of southerly or northerly winds at different periods of the year. During the height of spring tides the water rushed into the Manchester Ship Canal through the locks and sluiceways at Eastham; and the velocities since the tidal openings had been closed were now considerably greater in places than the currents in the Suez Canal which he had mentioned. With regard to the very interesting question of the beam of vessels, it was known that of late years the beam of vessels had very much increased. The Author had mentioned that 48 feet was the beam which had been taken as a basis in deciding upon the width to be given to the widened canal in 1884; but since then there had been a considerable increase. The "Rome," which was launched in 1881, had a beam of 52 feet; the "Paris," in 1888, had a beam of 63 feet, and the "Campania" and "Lucania," in 1893, had a beam of 65 feet; the "Kaiser Wilhelm der Grosse," in 1897, had a beam of 66 feet, and the "Oceanic," launched last year, 68 feet. If every vessel was to be allowed to go through the Suez Canal, it would be seen that the conditions were very much changed since the time when the question of the width of the canal was under consideration. He quite agreed with the Author that the question of depth was more important than that of width, for an inadequate width for vessels of maximum beam to pass could be got over, as hitherto, by special passing places; whereas an insufficient depth prohibited the entrance of vessels of large draught fully laden. It was well known that the vessels which had to go through the canal—the P. and O. vessels and others—on account of the canal being what he might call rather shallow, had been built so as to suit the canal, and not to suit what the companies would wish had they a larger limit. Probably the first thing to be desired was, that the depth of the canal should be increased. That, of course, was very important if all vessels were to be able

Mr. Vernon-Harcourt.

to go through a commercial highway of that kind. The "Oceanic" had a draught of 32½ feet, and of course it would be impossible for her to go through the canal. With regard to the protection of the banks, there was a certain amount of pitching between Lake Menzaleh and Ismailia; but certainly on the Arabian side, as far as he could see, when he went through the canal in 1896, the pitching was not everything that could be desired. A quantity of pitching was being done or repaired, but it was not in a very satisfactory condition, and seemed to be liable to be damaged by the waves which the steamer caused. It was most desirable that the pitching should be put into a sound condition. In the new sections, it would be seen that it was proposed to leave out the berm. He should like to ask the Author whether it was proposed eventually to carry out those suggestions, or whether he considered the berm, with the pitching to protect the slope above it, would be the most desirable. On account of the slow pace at which the steamers went through the canal, the wash was not very great. He had seen a greater wash caused by a much smaller steamer going at a greater pace down from Caen along the River Orne into the English Channel. He fully endorsed what the Author had said with regard to the enlargement of the canal, and as to the dredging operations not interfering with the traffic. Those operations were carried on at only a few places so as to be hardly noticeable in passing through the canal. It was not the dredging that interfered with the traffic, but the necessary tying-up which caused delay to the vessels. With regard to the electric light dazzling the pilots, he thought the members could easily realize that. If, on going out, on rather a dark night, in the country, one met a man carrying a lamp, on passing him he could not be seen, and one did not recover one's proper vision until some time after the man carrying the lamp had passed. That no doubt was the effect of the glare produced by the electric lights exhibited by a passing vessel, complained of by the pilots. It seemed as if the only plan of obviating that difficulty would be to use more ordinary lights. The electric lights were very powerful, making the banks look like snow; and they would require to be shaded temporarily at the time of passing. The question of the advance of the foreshore on the west side of the west jetty had interested him very much. The first thing he did on landing at Port Said was to visit that particular place. It could be readily seen from the curve assumed by the shore line that there had been an advance of the foreshore. He was very pleased to see from the chart of the Mediterranean at Port Said shown by the Author, that the pro-

Mr. Vernon-Harcourt. gression had been comparatively moderate since 1875. There was one curious point about it, namely, that though the lines of soundings inshore had altered very little to the west near the west jetty, the outside lines of soundings, especially the 11-metre line, had advanced considerably. It might seem difficult to account for that. No doubt there was also an advance further away west from the jetty, of the 9-metre line, and also the 10-metre line, though not in front of the canal. Curiously enough, in cases of the foreshore in front of the outlets of tideless rivers that had been surveyed, like the Mississippi and the Danube, it was found that the deltaic advance was greater in the deeper lines of soundings than in the shallower lines of soundings. It seemed probable that the reason why there was not so much advance in the less deep lines of soundings at Port Said, was partly because the drifting sand had been allowed to go through the holes seen in the breakwater, and which looked as if they were caused by Nature, though they were really caused by man, into the channel, and partly also because the west breakwater, offering a kind of obstruction to the flow of the turbid current from the Nile. This current was very clearly seen outside the end of the western breakwater, and the obstruction diverting the current prevented the introduction of the muddy water into the angle between the breakwater and the shore, and permitted the deposit to be greater where the current was not impeded, and where the current could pass more freely and slowly in those greater depths of about 11 metres. The advance of the sandy shore line might probably be attributed to the easterly drift caused by waves during storms. It might be hoped that this advance would not for some time to come, though it might of course in the future, necessitate an extension of the western breakwater.

Sir Edwyn Dawes. Sir EDWYN DAWES said that he had perhaps profited as much as anyone in the room by reading the Paper. He did not know that it was to his credit to say so, as he ought, as a Suez Canal Director, to know a great deal about the canal. He had, however, much pleasure in saying that reading the Paper, and seeing the sketches and photographs, had been most useful in making him better acquainted with the duties that devolved upon him. The only point he wished to refer to was that with regard to the depth of the canal. The Author had done perfectly right in pointing out that an increased depth was of the most urgent consequence. Already shipowners were clamouring to have the depth increased. The demand had been made especially by the Germans who were employing ships of greater capacity than the

English lines and, wishing to proceed farther in that direction, they had made a direct request to the Company that steps should be taken immediately to deepen the canal. Naturally there was much hesitation in complying with the request, considering the vast amount of money that had only just been spent in enlarging the canal. There could be no doubt, however, that this question would have to be met; and met at a very much earlier period than was thought likely when those extensive works were undertaken. The kindness and courtesy Sir John Wolfe Barry had received from his French colleagues had been mentioned. Sir Edwyn Dawes, as a Director of the Suez Canal, could confirm that. Nothing could exceed the kindness and hospitality with which the English Directors of the Suez Canal were received by their French colleagues at their monthly visits to Paris. A great deal had been heard about friction between the two nations, and rather unpleasant things had appeared in the French papers, and his friends, when he had returned from Paris, had occasionally asked him what sort of a reception he had had. He was, however, pleased to be able to say that nothing could be more agreeable, and that they had invariably been met with the greatest cordiality by their French colleagues. He ventured to think that if a dozen or so of Frenchmen had forced themselves on to a great English undertaking, as the English had forced themselves on the Suez Canal, they certainly would not have received a better welcome. Sir Edwyn Dawes.

Mr. C. J. Appleby remarked in writing that this very clear and concise record of the initiation and development of the works, which formed the world's highway between East and West, seemed to be interesting alike as a history of the canal and as marking the period when the advantages derived from the use of steam-driven machinery in constructive operations began to be at all generally recognised. The Author had himself contributed so largely towards perfecting the appliances and methods employed in the construction and maintenance of docks, harbours and waterways, that he naturally referred appreciatively to the efforts of Mr. Lavalley in that direction. Imperfect and inefficient as the plant was, compared with the splendid machinery now in common use, the number of workmen was enormously reduced—at that time a matter of the first importance—and the rate of progress greatly accelerated. The experience gained during the formation of the Suez Canal had undoubtedly contributed materially towards the improvements subsequently effected (principally by members of the Institution) in the mechanical Mr. Appleby.

Mr. Appleby. combinations included in the generic term "contractors' plant," but the younger members of the profession could scarcely realise the make-shifts their predecessors had to put up with 40 years or 50 years ago, when suction-dredgers, steam-cranes, excavators and many other machines now universally employed were entirely unknown. With regard to the labour question, those who had had occasion to see much of the conditions of life in Egypt would best appreciate the serious inconvenience and loss caused by the withdrawal of enormous numbers of the "fellaheen" from their ordinary occupations (chiefly agricultural) for employment on the canal-works at a time when the supply of agricultural machinery was extremely limited. This, together with the exceptionally high mortality amongst the workmen, caused serious disquietude. The substitution of machinery for the manual labour previously indispensable completely remedied this state of things. The facts mentioned in the Paper relative to the value of the shares purchased by the British Government in 1875 for £4,000,000, fully confirmed the opinion expressed to him by the Khedive on the day the arrangements were completed. After giving the details of, and the reasons for, the sale, His Highness had remarked significantly: "This is the best investment, financially and politically, ever made, even by your Government, but a very bad one for us."

Mr. Bell. Mr. J. R. Bell observed in writing that he had been employed in Egypt when the Sweet-Water canal—the key of the maritime canal's position—was being made. That work was understood to follow the route of more than one ancient canal which, in conjunction with the Lower Nile, afforded a communication from sea to sea. Those ancient projects were opposed by the priests as "beneficial to foreigners"—a narrow but accurate prognosis. Before the present "Rigole des eaux douces" reached Suez, that town and port were supplied with three or four train-loads of Nile water daily. The Cairo-Suez Desert Railway was now pulled up, but its method of supplying water had survived on various Indian frontier railway constructions. The tidal diagram of the maritime canal exhibited by Mr. Vernon-Harcourt, showing a preponderating ebb in opposite directions at different seasons, accounted for the singular freedom from malodorous stagnation in the sea-canal. In days when the evils of war were very prominent it might not be out of place to recall some of its compensations. From what he saw at the time, he thought that, but for the effects of the American Civil War, the Suez Canal might never have been completed. Much money and effort were frittered away with

hand-labour in the early sixties. Dredging was perforce used at Port Said and in Lake Menzaleh and indeed it all but ruined the plucky Scotch contractors who first took up that end. The American War brought things to a crisis, and when Egyptian cotton touched 2*s.* 6*d.* a lb., the Pasha found it easier to pay the Company in cash than to provide the promised forced labour. Just as the Napoleonic wars caused a demand in the North for "horses that lived on coals," so did the War of Secession raise Egypt's need for navvies with similar capabilities; and just as George Stephenson's genius produced the locomotive, so did Mr. Lavalley's the trough-dredger—prototype of modern steam-excavators. The saving effected by throwing the detritus directly on the flanking spoil-banks, instead of barging it out into the shallow seas at either entrance, was immense, even in those reaches which lay near the ends of the canal. In a recent type, called for by the widening of the canal and the superwidening of the spoil embankments, the trough was carried on a distinct hull, and could be slewed round, fore and aft of the waterway, when ships wanted to pass. There was also a very fine modern tool on the canal, a rock-breaker for deepening on the limestone reef under Serapeum. The rock was discovered exactly where Sir John Hawkshaw predicted it would be found. Residents in Egypt of those days were more impressed with Sir John Hawkshaw's sound and measured judgments than with those of all the other engineers ever consulted. It might be permissible here to suggest that the world hardly gave the Emperor Louis Napoleon enough credit for his pertinacity in backing up Mr. de Lesseps through thick and thin. As to depth of water, the canal already passed all the craft that could safely negotiate the Hooghly. Those who had passed through the canal need not be reminded that the ship tended to "sit down" in the trough between the wave she pushed before her and that which followed her up. Experienced navigators claimed that some ships sat down a foot in the canal, and in spite of an extra leaf abaft the sea-going rudder, many vessels steered so indifferently that few Companies using the canal cared to run the extra risk in twin-screw ships of striking the bank and losing a blade or two. The passage through the section between Suez and the Bitter Lakes with a following tide had always seemed to the nautical layman peculiarly hazardous, and it was current sea-gossip that the traffic manager tried to avoid that risk by tying ships up for hours. If so the tacit intention might well be avowed, and ships would try to make Suez in time to go up in a procession against the ebb. It would interest some engineers to know how the sea-soundings off Port

Mr. Bell.

Mr. Bell. Said were taken. The movements of the contours seemed to be measured by inches almost, and even at Alexandria westerly winds backed the whole Mediterranean 6 inches or more. Lead-line soundings, referred to the level of a cutter's gunwale, would not be accurate enough for settling sea-bottom contours in broken water. Perhaps sounding-rods were read from the shore a mile or more away by some special levelling instrument.

Dr. Corthell. Dr. E. L. Corthell contributed the following correspondence on the subject:—He desired to refer to only one point in the Paper, viz., the depth of the channel. It was an interesting coincidence that, at the time the Paper was under discussion, he had been engaged in writing a Paper for the International Congress on Navigation about to be held at Paris, in which he predicted that a depth of 31 feet (9·50 metres) would be necessary by the end of the next quarter of a century. During the past 3 years he had investigated this matter very carefully, and had given, in a Paper[1] read before the American Association for the Advancement of Science, many facts of this special subject of dimensions of vessels, and also the reasons for the rapidly increasing draughts. He worked out from the records of the earlier steamships, and through successive periods up to 1898, the loaded draught of the twenty largest steamships, and predicted that in 1923 the draught would be 31 feet, and in 1948 33 feet. Since that time he had obtained more recent information, all confirmatory of the opinion expressed in 1885 by the Author, that a depth of 31 feet would be found necessary in the Suez Canal. All of the very deep draught vessels were not transatlantic liners. The draught of the ordinary cargo-steamship was rapidly increasing. As to Atlantic liners, there were at the beginning of 1899 at least thirty-four with a loaded draught of 28 feet and over, nineteen of 29 feet and over, nine of 30 feet and over, and four of 31 feet and over. Of the regular steamship lines trading at the port of New Orleans, which might be taken as a characteristic first-class American port, and where the present available depth (not through the South Pass jetties, where the depth was 30 feet, but within 12 miles of the South Pass itself) was nominally 26 feet, but really not over 25 feet, the loaded draught was as follows: forty-two vessels with a draught of more than 26 feet, thirty over 27 feet, fifteen over 28 feet, ten over 29 feet, two over 30 feet, and two with a draught of 30 feet 9 inches. The view expressed by a

[1] "Maritime Commerce, Past, Present and Future," Proceedings of the American Association for the Advancement of Science, vol. xlvii., p. 580.

Dr. Corthell. large number of the experts upon the question submitted to them by the Sub-Commission in 1884, viz., that there should be 3 feet or $3\frac{1}{2}$ feet of water under the keel of a vessel moving at any speed, was borne out by the experience of pilots and navigators elsewhere. With less depth than this under the keel it was difficult to steer a vessel in a restricted channel, a fact which had been frequently noticed in the channel through the South Pass, where there was often a restricted depth under the keel. It might be mentioned that the proposition now before the United States Congress for the deepening of the mouth of the South West Pass of the Mississippi River, which was about five times the size of the South Pass, provided for a depth of 35 feet throughout the channel. The depth of channel provided for the entrance to New York Harbour, the contract for which had been made by the Government, was 40 feet; and it was proposed at Philadelphia, Baltimore and Boston to make channels 30 feet deep—in all cases below low water. There were the strongest possible reasons from every point of view—navigation, construction and economy—for deepening the channels into all first-class ports to allow of the free movement of steamships drawing, when fully loaded, 31 feet.

Mr. Fülscher. Mr. Fülscher, of Berlin, remarked in writing that he entirely agreed with the Author that the depth of the enlarged canal ought not to be less than 31 feet (9·50 metres) at low water of spring tides. Within the last few years a large number of ships had been built, having a maximum draught ranging between 27 feet 10 inches and 29 feet 6 inches, and when fully loaded such ships could not navigate the canal with a minimum depth of water of 29 feet 6 inches. The depth was not yet sufficient to meet the requirements of the world's commerce, and he felt convinced that the directors would very soon find themselves forced to provide for further deepening of the canal, not merely to 31 feet (9·50 metres), but to 32 feet 9 inches (10 metres), the depth considered desirable by the Author. With regard to the experiences of the Sub-Commission on their journey through the canal in the "Austral," he could confirm them from the results of trial runs through the Kaiser Wilhelm Canal. Vessels capable of making 16 knots per hour in the open sea, and having an immersed midship section of about 1,400 square feet, only made between 5 knots and 6 knots per hour for the same expenditure of power when passing through that canal, which had a cross-sectional water-area of 4,520 square feet. Even at this speed the action of the resulting waves was so violent that the bottom and slopes of the canal were considerably affected. A speed of between $3\frac{1}{2}$ knots and 4 knots per hour was attained

Mr. Fülscher. with a much more proportionate expenditure of power, and at this speed no damage whatever was done to the canal banks. Vessels having an immersed midship section of between 645 square feet and 753 square feet, being about one-sixth of the cross-sectional water-area, traversed the canal without undue expenditure of power, and without causing objectionable waves, at a speed of about 6½ knots per hour. According to the latest regulations of the Kaiser Wilhelm Canal, the speed of ships with a deeper draught than 16 feet 5 inches was limited to 6·5 knots (12 kilometres) per hour, and that of smaller vessels to 8·1 knots (15 kilometres) per hour.

Mr. Wells. Mr. LIONEL B. WELLS communicated the following remarks:— In 1898 he had visited Suez, and travelled along the canal thence to Ismailia. The passage occupied from 3.30 P.M. until 10.45 P.M., the average speed, irrespective of stoppages, being therefore more than 6 knots per hour. The steamship was 320 feet long, 39 feet wide, and drew about 21 feet, her gross tonnage being 2,260 tons. He was told that 11 knots was good speed at sea. In the canal 8 knots per hour were made at times, for the regulation as to maximum speed (5·33 knots per hour) was disregarded. The canal was divided into sections with stations 7 knots apart, and ships were forbidden to pass from one section to the next until the allotted time had expired. As soon, however, as the pilot entered a section he drove the ship as hard as he could and slowed to wait for time before entering the next section. The wash was considerable and the banks suffered damage. The passage of the vessel drew the water off the berm, which showed much wider on the east than on the west side, dredging for the enlargement of the canal having probably taken place on the west side only. The tide being against the vessel, she had to moor in order to allow two ships, one of which drew 25 feet 9 inches, to pass towards Suez. This caused a delay of 50 minutes. At the back of the berm a dry rubble stone wall was built to a few feet above high-water mark, and in places small round piles were driven at the foot. The protective works appeared to have given way in many places, particularly where piles had not been driven. Having in view the expansion of trade and the rapidly-increasing size of ships, any expenditure likely to curtail the enlargement of a canal should be undertaken with reluctance.[1] In places the deposit of the original

[1] The Ghent Canal, which was widened and deepened to 21 feet twenty years ago, is now being enlarged and deepened to 26 feet.

excavation too close to the channel was already giving trouble, and in such places protective works were more necessary than elsewhere. He had also visited El Guisr where the deepest cutting occurred. The foot of this had been substantially piled in places. The estimate for the enlargement of the works gave the whole cost of excavation and dredging 69,625,000 cubic metres as £8,300,000 = 2*s.* 4·6*d.* per cubic metre, whereas the actual cost of dredging was stated to be upwards of 1*s.* a cubic metre—a most satisfactory diminution of expenditure. It would be interesting to know how this had been accomplished. Mr. Wells.

The Author.
THE AUTHOR, in reply, observed that his task had been made lighter by the remarks which had fallen from the lips of Sir John Wolfe Barry, his English colleague in the International Technical Commission, who in his unavoidable absence had voluntarily taken charge of his Paper and had prepared the diagrams displayed on the walls of the meeting room. He was glad of this opportunity of returning his hearty thanks to his colleague for this friendly act, and also of confessing publicly that but for Sir John's repeated requests the Paper would never have been written; not only because the Author keenly felt his inability to write a history of the canal *in extenso* which would be worthy of publication, but also on account of the difficulties to be surmounted even in an attempt to epitomise accurately and in a readable form the principal facts and figures of so vast a theme within the limits of an ordinary Institution Paper. Reference had been made by Sir John Wolfe Barry to an interesting matter connected with the dredging operations at Port Said, namely, that the engineers of the canal had happily hit upon the idea that it would be advisable to attack the deposits passing through the interstices of the west jetty, which was almost entirely composed of large concrete blocks thrown down at random, by dredging the newly-deposited sand under shelter of the jetty instead of beyond its head in the open sea. In order still further to check the growth of the sand-bank seaward, the plan had also been adopted during a period of several years of removing and replacing from time to time portions of the superstructure of the jetty, near its root-end, to allow the sand driven westward through the gaps during gales to enter the canal, where it could be easily dredged away. This rough method of breaking up and restoring the superstructure of the jetty over a length of about 300 yards had lately been superseded by the construction of a roadway from the shore, supported at its outer end by sixteen arches of masonry, each of 20 feet span, through which the sand now travelled freely in stormy weather. In connection with this

The Author. new arrangement it might be interesting to remark that the roadway in question led to and ended at the artistic monument of Count Ferdinand de Lesseps, which was unveiled by the Khedive in brilliant weather and with imposing ceremony on the 17th November, 1899, the thirtieth anniversary of the opening of the canal; and that the site of the monument (which was a fine colossal bronze statue with the legend "*Aperire terram gentes*" greeting every ship entering the harbour) was situated on the west jetty at a distance of 3,034 feet from the original shore line in 1859, but only 1,066 feet from the present *terra firma* at the north end of the Francis-Joseph Quay. He shared the opinion of Mr. Vernon-Harcourt that probably the slow advance of the less deep lines of soundings as compared with the more rapid advance of the 11-metre line, was partly because the sand had been encouraged to pass freely through the open block-work of the west jetty into the channel leading to the canal, whence it was readily removed by dredging. It was evident, moreover, that the constant dredging that had been done immediately off the entrance had also largely contributed to retard the advance of the shallow lines of soundings for a considerable distance westward of the west jetty. The sea-soundings were taken by means of the lead-line and sextant in conjunction with transit poles and landmarks, and the results were given in metres and decimetres reduced to a low-water datum. With regard to the height and velocity of tides in the Suez Canal, he agreed with Mr. Vernon-Harcourt that, broadly speaking, the differences in the level were mainly due to the wind at different periods of the year. He would supplement Mr. Vernon-Harcourt's valuable information on this subject by the statement that, according to observations with the self-registering gauge at Port Thewfik, the maximum range of tide at Suez during each of the three years ending the 31st August, 1897, 1898, and 1899, was 7 feet 7 inches, 8 feet 3 inches, and 8 feet 6 inches respectively, the highest rise being in winter and the lowest fall in summer, whilst at Port Said during the same period the extreme range never exceeded 4 feet 6 inches. Touching the dilapidated condition of certain portions of the revetments of the banks of the canal, it should be remembered that the provisional character of the stone-pitching over several long lengths of the canal, either on one bank or the other, would probably, for the sake of economy, remain in that condition up to the time when the ultimate widening of the canal had been accomplished; and, as an example of the transition-stage of bank-protection at the present period, it might be mentioned that from Port Said to

The Author.

Kantara, a distance of 24 miles, the stone revetment of the African bank was all but completed in a substantial manner, in the way described by Sir John Wolfe Barry; whilst the opposite Asiatic bank, in view of a further enlargement on that side of the canal, was only partially, and very inadequately, protected from the wash of passing steamers. Hence the eastern slope seemed to the eye of a passer-by to be in a very unsatisfactory condition, and the same remark applied to many other sections of the canal where further enlargements were in contemplation. It should be further remarked that at certain parts of the waterway, the Engineer-in-Chief proposed to protect the upper part of the slopes, and had already protected it over a length of several miles, with plantations of reeds and tamarisks. That officer held the opinion that elsewhere in some cases, especially between the Ballah Lakes and El-Guisr, where hard natural slopes had been formed by the play of the waves, no bank-protection of any kind would ever be needed, or at any rate until the necessity for artificial protection had been proved by further experience. It had been decided to restrict the width of the berm or benching at the foot of the revetment to a maximum of 2 metres, as it had been practically demonstrated that a greater width was inadvisable. The remarks of Mr. Appleby and of Mr. Bell, contrasting the ingenious appliances employed at the present day in the construction and maintenance of harbours and waterways with the rude and inefficient, and therefore very expensive, methods employed in the "Fifties," were much to the point; and, in illustration of the great value of the improved appliances of modern times in substitution of hand-labour and inefficient machinery, it might be pointed out that during the last few years, dredging in the open sea had become an ordinary engineering operation, and now presented no difficulties provided that the dredging plant was of adequate size and properly designed for the purpose. Mr. Bell had remarked that before the opening of the canal, "residents in Egypt were more impressed with Sir John Hawkshaw's sound and measured judgments than with those of all the other engineers ever consulted." Although this assertion was probably correct, he considered that it was only fair to add that the public mind in the British Isles, as well as in Egypt, was also much impressed in favour of the great international work about the time of the opening of the canal, and therefore long before its complete success was assured, by the famous Admiralty Report of General Sir Andrew Clarke, and Admiral Richards in 1869, and by the Official Report made in the same year by the late Sir John Fowler, Past-President Inst. C.E., the Engineer-in-

The Author. Chief at that time for Egypt and the Soudan. The remarks of Dr. Corthell on the advisability of providing an ample depth of water in maritime canals and harbours for vessels of the largest class, were a valuable contribution to the Discussion, coming as they did from an expert of high authority in the United States on all matters connected with the safe navigation of vessels in contracted channels. He was gratified to notice that the conclusions arrived at in this respect by Dr. Corthell were fully shared, not only by Sir John Wolfe Barry and Mr. Vernon-Harcourt, but also by two other distinguished authorities of European reputation who had contributed to the Discussion orally and in writing, namely, Sir Edwyn Dawes of London, and Mr. Fülscher of Berlin. In short, there seemed to be a consensus of opinion in favour of providing an ultimate depth of 10 metres (32 feet 9 inches) in the Suez Canal from sea to sea, as he had ventured to recommend.

Sect. II.—OTHER SELECTED PAPERS.

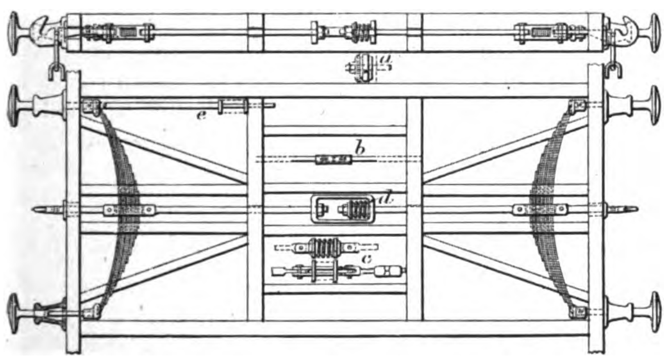
(Paper No. 3058.)

"Failures in the Draw- and Buffing-Gear of Railway Wagons."

By George Tertius Glover, Assoc. M. Inst. C.E.

The most frequent, although perhaps not the most serious, casualties to goods or mineral trains are those occurring in the draw- and buffing-gear of the rolling stock. The arrangement of the gear used by many railway companies, and approved by the Clearing House for private owners' wagons, is shown in *Figs. 1.* The draw-gear is continuous and elastic, having laminated springs to take the buffing and drawing stresses, and a cradle with india-rubber (*a*) or spiral springs (*d*) to render the drawbar elastic. Cotter-boxes

Figs. 1.



Scale, $\frac{1}{16}$ inch = 1 foot.

Arrangement of Draw- and Buffing-Gear for Wagons.

(*b*) are used in a number of wagons (principally those belonging to private owners), and the "Bowles" method is also used, which consists in inserting a spring (*c*), thus avoiding the weight and the welding involved in the ordinary design of cradle. Any spiral or india-rubber spring may be employed.

With the exception of a few fish- and meat-vans for use in passenger trains, the system of loose coupling is adopted, partly for convenience in coupling and uncoupling, but chiefly to enable the engine to start a heavy train with ease, by starting each wagon

separately. The gear is thus liable to severe shocks during starting, stopping, and shunting. The failures in the buffing-gear are few and unimportant when compared with those in the draw-gear. Couplings are sometimes broken while running, as when a long goods train is turning the top of a bank, and the engine and the first few trucks commence to run down hill before the tail-end has crossed the top, thus throwing an additional stress on the couplings, causing a "break-away," when the rear portion either runs back or runs ahead, overtaking the front portion (which is being slowed up on the driver missing the remainder of his train), with serious damage to the rolling stock. Double coupling, *Fig. 2* (*c*), may save an occasional "break-away," but it undoubtedly causes much breakage of couplings and hooks.

Causes of Failure.

Of the various causes of failure, rough usage may be considered the most frequent. The actual stresses induced by this cause cannot be reduced to exact figures, but the fact that couplings are in use, the links of which have collapsed between ½ inch and ¾ inch, an amount which requires a total stress of 20 tons to 23 tons by a steady pull in a testing-machine, indicates the severity of the sudden shocks on the draw-gear. The pull on the draw-gear when starting a heavy train is approximately shown by the following example:—In a train of forty wagons with a load of 10 tons and tare of 6 tons, and with a starting resistance of 20 lbs. per ton, the weight of the train would be $40 \times (10 + 6) =$ 640 tons, and the total resistance $\frac{640 \times 20}{2240} = 5 \cdot 7$ tons. In tests made with a dynamometer van, however, the sudden jerk in starting a heavy goods train with loose couplings has produced a stress in the draw-bar equivalent to a steady pull of 11·5 tons.

Wrought-iron buffer-heads are often found to be indented by continual striking on the socket, so that the force on the buffing-gear to produce such a result must frequently be far in excess of the 3 tons to 4 tons required to overcome the resistance of the spring. Flaws are largely the result of rough usage, and are not easily detected when the wagon is in use, as the outside gear is exposed to the weather, which rusts over any slight crack, and the internal gear is not readily accessible. In some cases, in which broken material has been examined, the fracture has been so dirtied and rusted that the existence of a flaw has been doubtful. As a rule, however, in the case of sound material, the crystalline texture can be seen after the dirt has been removed.

Wear is chiefly noted in the draw-gear pins and eyes, in the ends of coupling-links, and in buffer-sockets. Crushing occurs in cotters and cotter-boxes, some of the latter being very light in section. Fatigue in the spring-steel results in loss of camber of the spring, and causes the rubber to become hard and inelastic. Faulty design is not a common cause of failure, the officials of the various railway companies having given thought to the working out of the details, and the private owners being tied down to a standard design approved by the Railway Clearing House. A large number of old wagons are in use, containing unsuitable parts, such as draw-hooks of small section, small draw-bar eyes, and cotter-boxes. The great want of uniformity in these is shown by *Figs. 6*; while in use any one of these hooks was liable to have the maximum force transmitted to it, although the sections varied as much as 50 per cent. Draw-bar pins appear to be the weakest portion of the draw-gear, as in no other part is so much sound material found broken, but it is as well that, in case of overstrain, the gear should give way at a point such as this, where repairs can be easily and cheaply executed.

The relative frequency of failure of the various parts of the gear, out of a total of 2,900 failures, was as follows:—

Draw-Gear.				Buffing-Gear.
Couplings.	Hooks.	Draw-bars.	Springs.	
Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
48	18	28	4	2

Draw-Gear.

a. Couplings.—These receive the first shocks incidental to pulling the train, and therefore constitute the most fruitful source of failure. The following Table gives the number and causes of failures during a considerable period, as shown by examination of 1,374 couplings broken in working the traffic:—

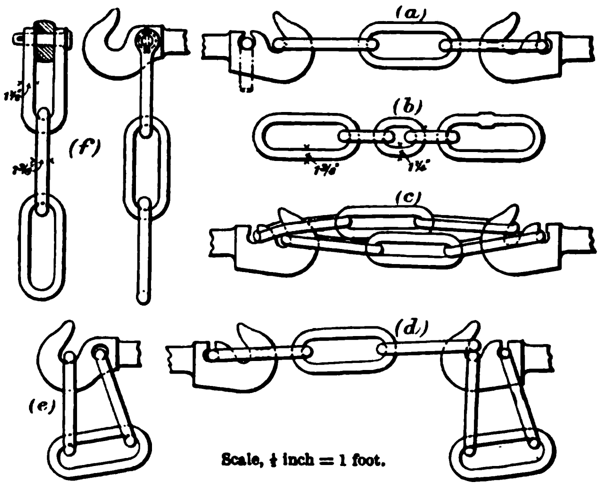
Table I.

Owned by—	Rough Usage.	Flaw.	Unsound Weld.
	Per Cent.	Per Cent.	Per Cent.
Railway Company	42·7	26·9	30 5
Private Firms	22·4	19·2	58·4

The three-link coupling, $1\frac{3}{8}$ inch in diameter, is now chiefly in favour, the old five-link chain, as well as the shackle and pin, have been discarded, as the chain only contained more links liable to failure, and the shackle and pin, *Figs.* 2 (*f*) (which was never a satisfactory arrangement, the pins failing and getting lost, etc.), cost nearly 10 per cent. more, owing to the greater amount of work involved in its manufacture. The shackle, when subjected to an extra rough shunt, would close in and bind on the draw-hook shank, becoming so stiff as to cause considerable danger to the shunter, especially when coupling with the pole.

Many companies prefer Gedge's coupling, *Figs.* 2 (*a*) and (*b*), in

Figs. 2.



METHODS OF COUPLING.

which a flat part on the last link slips through a slot in the draw-hook; the alternative plan, *Fig.* 2 (*e*), consists in putting the last link unwelded through a hole in the draw-hook and then welding it up. This is rather more expensive, the price per ton for wages being higher, as the welding of the end link is more awkward to perform and less reliable; hence this link is made of iron $1\frac{7}{16}$ inch or $1\frac{1}{2}$ inch in diameter.

Side chains, $\frac{7}{8}$ inch in diameter, are being abandoned in modern wagon practice; they are found to be of slight use, as when the centre chain gives way the front portion of the train gains additional momentum to snap the side chains. The links, also, are of weak form, as they have to be "thrown wide" in order to admit the

hook, and the wider the links are made the weaker the chain becomes. Side chains are sometimes not of equal length, and the shock thus coming on each separately, breaks them at once. If these chains are used they should be specified to stand a total stress of at least 18 tons.

Couplings should be made of high-class chain-iron (giving about 35 per cent. elongation in 4 inches, and 45 per cent. reduction in area, with a tensile strength of 22 tons to 23 tons per square inch); when side-welded they should stand a pull of at least 50 tons before breaking, this being equal to a stress of 16·83 tons per square inch, and if end-welded they should stand 35 tons to 40 tons total stress, equal to 11·7 tons to 13·4 tons per square inch. Out of the last twenty couplings (representing 1,000) tested by the Author, the range was between 55·2 tons and 63·7 tons total stress, and the average was 59·2 tons total stress, equal to 19·5 tons per square inch. The best method to secure a good class of coupling is to test to destruction samples taken from bulk, say, one from every fifty, and to specify a minimum breaking load. No proof load (as in ordinary close-linked chain) can be specified, as the maximum load which could be applied without causing the links to collapse would be too small to be of any practical value. In close-linked chain, the ratio of minimum breaking load to proof load is 2·25 to 1, which gives, for $1\frac{3}{8}$-inch coupling of 50 tons minimum breaking load, a proof load of 22 tons, which would collapse the links $\frac{5}{8}$ inch, as shown by the following experiments:—

TESTS SHOWING COLLAPSE OF CENTRE LINK IN 3-LINK COUPLINGS.

Load Applied.	Inside Width.	5 Tons.	10 Tons.	15 Tons.	20 Tons.	25 Tons.	30 Tons.	35 Tons.	40 Tons.	Breaking Load.
										Tons.
Collapse in inches.	$3\frac{1}{8}$	..	$\frac{1}{16}$	$\frac{3}{16}$	$\frac{5}{8}$	$\frac{15}{16}$	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	58
	3	..	$\frac{1}{32}$	$\frac{3}{16}$	$\frac{17}{32}$	$\frac{7}{8}$	$1\frac{1}{8}$	$1\frac{3}{8}$	$1\frac{9}{16}$	63·7
	3	..	..	$\frac{1}{8}$	$\frac{7}{16}$	$\frac{13}{16}$	$1\frac{1}{16}$	$1\frac{5}{16}$	$1\frac{1}{2}$	not taken.

The private owners' specification requires chains to be made of $1\frac{3}{8}$-inch best cable iron, Government chain quality, pins and shackles not to be used.

Steel couplings are rarely used; they are less reliable than those of iron owing to the difference in welding properties, the range of temperature at which sound welding takes place being so small. The gain (in the original bar) of 4 tons per square inch in tensile strength over that of wrought-iron, *i.e.*, from 22 tons per square

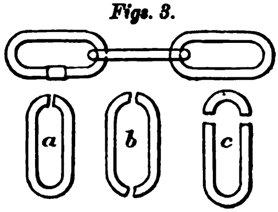
inch to 26 tons per square inch, is too small to counterbalance the unreliability in welding.

TABLE II.—BROKEN WAGON-COUPLING LINKS.

Railway Company.					Private Owners.				
Cause of Failure.	Elongation in 2 inches.	Reduction of Area.	Ultimate Stress.	Bending.	Cause of Failure.	Elongation in 2 inches.	Reduction of Area.	Ultimate Stress.	Bending.
	Per Cent.	Per Cent.	Tons per Sq. In			Per Cent	Per Cent.	Tons per Sq. In.	
R. S. Slight flaw .	42·5	37	23·30	Close Cracked.	Rough Shunt	..	..	..	Close Cracked.
Rough Shunt .	..	..	..	150° Cracked.	Unsound	14·0	41	22·7	Close Good.
Flaw . .	39·5	35	23·53	Close Cracked.	Unsound	6·5	40	22·9	Close Good.
Flaw . .	34·0	32	23·85	Close Good.	Unsound	..	..	..	40° Broke.
Flaw . .	41·5	47	23·75	Close Good.	Flaw and Unsound	..	..	..	Close Good.
Unsound .	51·5	55	23·68	Close Good.					
Unsound .	46·0	43	23·26	Close Good.					
Flaw and Unsound	..	..	..	170° Cracked.					

The term "best cable iron" is vague, and some of the material classed as such is not fit for use in wagon couplings. Table II shows the results of tests of the straight parts of broken couplings (tensile and bending test-pieces being taken from opposite sides); on the whole these show good material, one test-piece in particular being B. Y. chain quality, but the weld in this case was of the worst description.

Figs. 3.



Scale, ¼ inch = 1 foot.

TYPES OF FAILURES.

The various causes of failure will now be dealt with in detail.

Rough Usage.—As will be seen from Table I, this is the cause of about 38 per cent. of all the coupling failures. Failures due to this cause group themselves as three different types (*Figs. 3*). First a plain break (*a*) across the end of the link, which opens and allows the other link to be drawn out; the fracture usually occurs at the welded end, where pockets, due to unsoundness in the scarfs, no doubt weaken the links at the point of maximum bending moment,

but often the two ends appear to break simultaneously (*b*), the halves then falling on to the line. The third type of failure is shown at (*c*), the whole crown of the link coming away at the welded end; the fracture occurs first at one end of the scarf, the link then opening and snapping off at the other end. The fractures have a crystalline appearance, due to the sudden shock with which the links have been broken, but a coarsely crystalline structure, with large facets, is undoubtedly an indication of inferior iron. *Fig. 4* (*k*) shows a piece broken right out of the end of a side-welded coupling, which, as the fracture proved, was made of an excellent quality of iron; no material can be expected to stand such usage as this indicates. In investigating the cause of a fracture, the section of the hook that the link was on at the time of failure must be considered, as sections such as that shown in *Fig. 6* (*b*) and *Fig. 7* (*c*), now almost obsolete, tend to produce fractures of this sort. Many end links are bent, *Fig. 2* (*c*), and a large number of all three links are probably broken by double coupling, but the evidence of this is not so clear as in the case of draw-hooks, as no distinctive marks due to this appear on the links.

Flaws.—These account for about 25 per cent. of coupling failures, and a large number of them are caused by rough usage, which has strained the material and started slight cracks, which have gradually enlarged, as shown in the fracture by the rusting which has taken place in the flaw. Inferior material, laminated iron, overheating in the manufacture of the links, etc., soon start flaws, which lead to breakage. Some flaws are caused by the smith, in his anxiety to make a finished-looking weld, giving it, when at a dull red heat, needless dressing with the light hammer, which tends to crystallize the iron and causes it to give way under working stress in minute transverse cracks. Red-shortness, if excessive, also causes failures of a similar nature at both ends of side-welded, and at the unwelded ends of end-welded links.

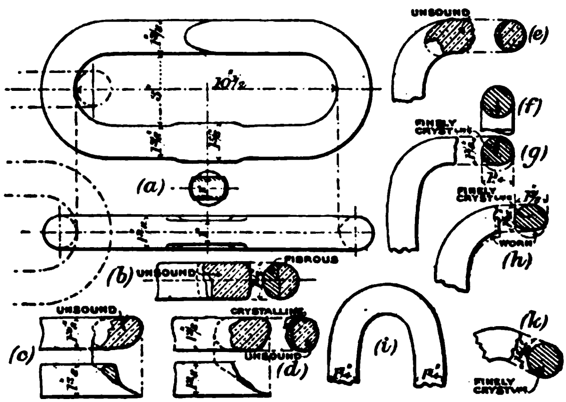
Unsound Welding.—This class of failure may be due to (1) dirt; (2) insufficient heating; (3) overheating; (4) overworking by the smith. Dirt occurs from slag and scale and the cause of its presence in the finished weld is carelessness in clearing the scarfs. Overheating is indicated by a vitreous appearance of the surface of the link and by a sponge-like fracture. In reference to the over- and under-heating of the scarfs, it is found that the range of temperature at which iron can be properly welded is much smaller in the case of the best qualities of iron than for the common brands; the better qualities thus need greater care in heating; this is easily mastered by a good smith, who will avoid the last cause of weld

failure (also mentioned under "Flaws"), namely, overworking the weld, when cooling, with the light hammer, which opens the end of the scarf and causes crystallization.

Many railways use side-welded in preference to end-welded couplings, and the results amply justify the extra expense of 5*s.* to 10*s.* per ton, which is entailed in workmanship, on account of the ends having to be heated and bent separately to gauge, and adjustment for length not being so easy as in the end-welded links, since in the latter the scarf can be more or less bent as desired. Fewer side-welded links also can be kept in the smith's fire at one time, owing to the position of the weld.

End-welded links are in general not so sound as side-welded

Figs. 4.



Scale, 1½ inch = 1 foot.

FAILURES IN COUPLINGS.

links, as the former require an awkwardly curved scarf, 2½ inches to 3 inches long, which is more difficult to weld than the 1½ inch to 2 inches plain scarf at the side. The ends of the link have to take all the wear, and there is also at these points a bending action in addition to the tension; the full strength of the original bar should therefore be maintained here, and the weld (always at least 10 per cent. weaker than the original bar) should be placed at the side, where it has to resist tensile stress only. Small "pockets" (*Fig.* 4 (*f*)) are sometimes found at the inner edge of the crown of the links, where the scarf is most difficult of access; these when small have but a slight weakening effect and are usually classed as "Rough shunt—slightly unsound"; 2·2 per cent. were

so reported. These pockets are found in large chains (2 inches in diameter and over) even of the best make. The jars and shocks to which the links are subjected during work tend to crystallize the iron and to open even the soundest welds.

Examples of unsound welds are shown in *Figs. 4*, (*b*), (*c*), (*d*) and (*e*); some of these show hardly any sign of true welding. Several of these were at the sides of the links and in these cases all the advantages of side-welding (such as reliability in welding and full strength of iron at the ends, the weakest points of the links) have been lost on account of bad workmanship. The following Table (Table III) gives the results of breaking, in the testing machine, a large number of end-welded couplings which had been in use for at least 5 years; the poverty of the results must not be altogether ascribed to fatigue of the materials, unwelding by shocks during service, etc., as the majority gave way at the weld, showing an unsound fracture; also, a few years back, end-welded couplings often failed to stand a total load of more than 25 tons to 30 tons when under test, owing to inferior workmanship.

TABLE III.—OLD END-WELDED COUPLINGS 1⅜ INCH IN DIAMETER.

Annealed.			Unannealed.		
Total Load in Tons.	Tons per Square Inch.	Remarks.	Total Load in Tons.	Tons per Square Inch.	Remarks.
36·65	12·12	Slightly Unsound	22·78	7·85	.. ..
27·26	8·99	Slight Flaw .	24·12	8·32	Slight Flaw
28·60	9·43	" "	22·78	7·51	" "
22·78	7·51	" "	22·78	7·51	Slightly Unsound
25·02	8·25	.. ..	25·47	8·40	Flaw
28·15	9·50	Slightly Unsound	31·28	10·79	Unsound
32·63	10·78	Unsound	21·00	6·93	"
28·15	9·28	Slight Flaw	28·61	9·37	"
28·65	Average.		24·85	Average.	

Wear.—This cause of failure is simply loss of section at the ends, thus increasing the stress per square inch on the weakest point. Some couplings are kept too long in use. *Figs. 4*, (*g*) and (*h*), show losses of 20 per cent. and 25 per cent. respectively. The continual hammering at the ends of the links tends to crystallize them; annealing, after a certain number of years' working, would relieve this, and would enable the chain to run for a longer period even when the section is reduced. In Table III the annealed links show 15 per cent. greater strength than the unannealed, under the steady pull of a testing machine, but in the case of

suddenly applied loads (such as starting a train) the annealed links would probably show even to greater advantage.

β. Draw-Hooks.—Taken over a period of 1½ year, 523 of these failed as against 1,374 couplings.

The number was made up as follows:—

TABLE IV.

Cause of Failure.	Per Cent.
Rough usage	72
Flaw	20
Light section	5
Bad material	3

The hooks are forged with a short length of draw-bar, which is attached by pin and eye to the central draw- and buffing-spring, or, in some cases, direct to a length of draw-bar. They differ chiefly in the method of attachment of the coupling. This may be "Gedge's" slotted hole with the link slipped in, *Fig.* 2 (*a*), or a plain hole with the link welded in, *Fig.* 2 (*e*), or a pin and shackle, *Figs.* 2 (*f*).

Draw-hooks are usually forged to section, and then bent to a pattern either under the steam-hammer, or by a hydraulic machine. If stamped out, the grain of the iron should be kept running with the hook, an important point sometimes overlooked in second-rate work. The material should be best selected wrought-iron scrap, giving about 23 per cent. elongation in 4 inches, and 23 tons per square inch ultimate stress. When tested in the machine, the standard draw-hook shown in *Fig.* 5 (*a*) should stand about 45 tons before fracture.

In the following Table (Table V) are given the results of tests of such hooks, and of tensile tests of the forged draw-bar ends:—

TABLE V.—DRAW-HOOKS.

Total Breaking Load.	Tensile Test.			Calculated Ultimate Maximum Tensile Stress on Section AA, *Fig.* 5 (*a*).
	Elongation in 4 Inches.	Reduction of Area.	Ultimate Stress.	
Tons.	Per Cent.	Per Cent.	Tons per Square Inch.	Tons per Square Inch.
47·85	30·25	..	24·64	23·64
45·00	..	..	..	22·47
41·07	22 50	32	23·02	20·53
39·73	20·50	23	20·89	19·85
37·94	24·75	31	23·80	18·97

Hooks are subjected to two stresses, namely, a direct tensile stress $\frac{W}{a}$, where W = load, and a = area of cross section, superposed on a bending stress $\frac{Wl}{Z}$, where Z = modulus of section = $\frac{1}{6}\, b\, h^2$, and l = distance of neutral axis of section from line of load.

Referring to *Fig. 5* (*a*), section AA:—

maximum tensile stress (at inner edge) $= \frac{W}{a} + \frac{Wl}{Z}$,

maximum compressive stress (at outer edge) $= \frac{W}{a} - \frac{Wl}{Z}$.

This formula is only meant to apply to stresses within and up to the elastic limit, and has been constructed on the supposition that the beam is made up of a number of infinitely thin layers independent of each other, and no account has been taken of the adhesion which exists between the fibres of the iron; hence, when dealing with ultimate breaking stresses, it can only be successfully used by the introduction of a coefficient "c," which varies (according to the section) between 1·5 and 2·5. For hooks of this section it is usually taken as 2.

Example.—Standard hook, *Fig. 5* (*a*), broken with a total load of 45·00 tons.

Maximum tensile stress on section A A, in tons per square inch—

$$= \frac{W}{a} + \frac{Wl}{Zc} = \frac{W}{a} + \frac{Wl}{\frac{1}{6}\, b\, h^2\, c}$$

$$= \frac{45}{6\cdot 81} + \frac{45 \times 2\frac{7}{8} \times 6}{2 \times (3\frac{1}{2})^2 \times 2}$$

$$= 6\cdot 6 + 15\cdot 875$$

$$= 22\cdot 47.$$

In his "Applied Mechanics,"[1] Prof. Cotterill, in treating of the breaking strength of beams, says: "As soon as the elastic limit is passed, the stress, at points near the surface, no longer varies as the distance from the neutral axis. It does not increase so fast, because the extension or compression is not accompanied by a proportionate increase of stress. Hence, a partial equalization of stress is produced, and the maximum stress for a given moment of resistance is reduced." Mentioning the adhesion of the layers, he says: "When the limit is passed, the connection between those layers which are most stretched and compressed with those layers

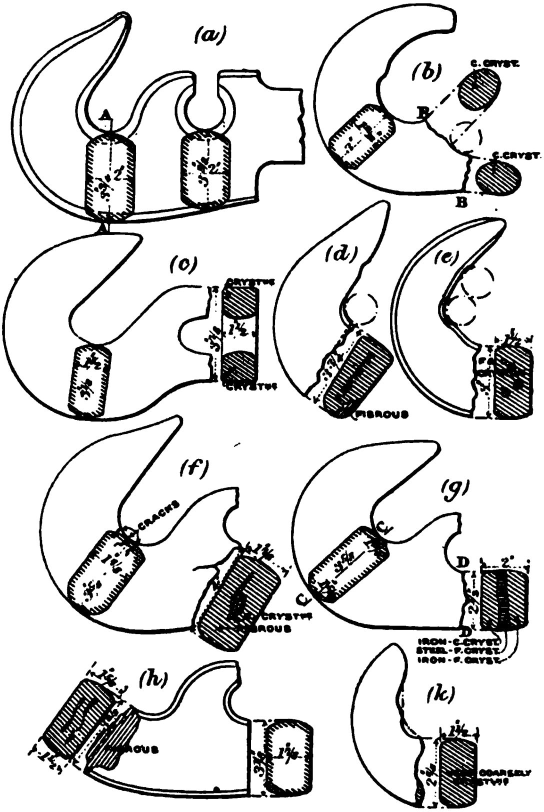
[1] 1895 edition, p. 428.

which have not yet lost their elasticity, prevents their contraction and expansion, and so raises the limit of elasticity. Thus the apparent elastic strength is greater in bending than in tension."

The various causes of failure will now be considered in detail.

Rough Usage.—This is the most frequent cause of failure, as it

Figs. 5.



Scale, 1½ inch = 1 foot.

FAILURES IN DRAW-HOOKS.

comprises 72 per cent. of the total number. As in the case of couplings, the hooks have to bear heavy shocks both in starting and stopping a train. Under this head comes double coupling, *Fig.* 2 (*c*), a bad practice that is so prevalent in some districts that the hooks show two points of wear, one for the normal position of the coupling link, and another higher up on the hook, *Figs.* 5

(*d*), (*e*), and (*k*). From the position of the link in double coupling, the bending moment on the hook is much increased, a working load is applied which the hook was not designed for, and an unknown side stress is introduced, owing to the twisting of the links. Some of the double marks are caused by the coupling having been hung up on its own hook, *Fig.* 2 (*d*). This practice, of course, increases the bending moment in the same manner as double coupling, but does not produce the same bad effects (especially on the couplings), as it causes no twisting of the links, but no useful purpose is served by it, as the ends of couplings are usually 8 inches above rail-level, and there is no danger of them striking any object on the line. Breakages caused by rough shunting show a marked crystalline fracture, due to the suddenness with which the break has occurred. In *Fig.* 7 (*e*) is shown a form of damage which is noticed in the hooks of mineral wagons. This is caused by striking the "centre bar" of old chaldron wagons, many of which are still in use on the collieries and docks of the north country.

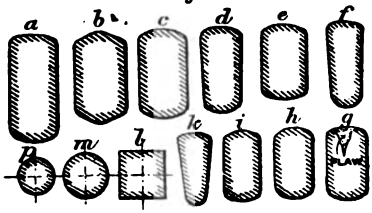
Flaws and Bad Material.—Next to rough usage, flaws are the most fertile source of failure. Many of them are doubtless caused by rough working, as they are found at the inner edge of the hook, the point where the maximum stress occurs. Very poor iron, as shown by the fracture, which consists of large, bright, crystalline facets, is worked into some hooks. It is of a class quite unsuited to stand the shocks to which draw-gear is subjected. Laminated draw-hooks occasionally occur, and are due to bad workmanship, *i.e.*, a want of care in piling the iron before forging.

Figs. 5 (*g*) and 7 (*a*) show fractures indicating a mixture of steel and iron. Although the different kinds of scrap are usually kept separate, still, with the amount of mild steel now in use, a small quantity of it sometimes gets into the pile. In these two cases it has probably been a small piece of plate. In both cases the welding was perfectly sound and the resultant material good, but if metal like this is used for parts requiring welding, the results are apt to be unreliable, owing to the different welding properties of iron and steel. Specially mixed metal, termed "Fibrous steel," is now on the market.

Light Section.—Under this heading are included all remarks on sections. The depth and area of section at the plane of maximum stress should be the same in all wagon hooks, as any wagon is liable to be placed next to the engine, and its hooks will then have to bear the whole force required to draw the train. The

great absence of uniformity in this respect is shown by *Figs. 6*, *a* to *k*; thus, comparing *a* and *h*, *Figs. 6*, the areas are in the ratio of 1 to 2, but this does not represent the ratio of the strengths of the two hooks, since the strength varies as $\frac{b\,h^2}{l}$; so that in this case the strengths are in the ratio 1 to 3. Section *a*, however, is the largest hook which has come under the Author's notice, and bears a ratio to the standard hook, *c*, *Figs. 6*, of 1·27 to 1 in sectional area, and of 1·5 to 1 in strength. The hook, of which *b*, *Fig. 6*, represents a cross-section, and which belonged to a 10-ton wagon, should never have been made; the bearing edge, instead of being rounded, has a ridge capable of cutting open any coupling-link crown. This hook has probably been the cause of numerous broken couplings.

Figs. 6.



Scale, 1½ inch = 1 foot.

SECTIONS OF HOOKS AND DRAW-BARS.

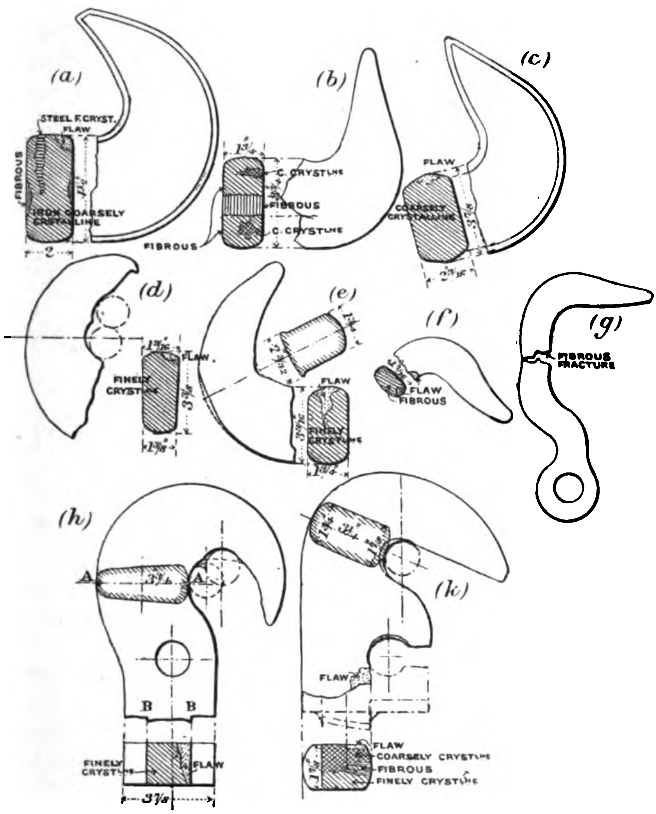
"Gedge" couplings occasionally fail through the metal beneath the slotted hole, as there is a bending moment at that point; thus, the hook shown in *Fig. 5* (*g*) had not sufficient area at D D, for the ratio of the moment of resistance of section C C to the moment of resistance of section D D is 21 : 11, while the ratio of the bending moment on section C C to that on D D is 21 : 15; thus at section C C the hook is 36·5 per cent. stronger than at section D D. The hook shown in *Fig. 7* (*k*) has been deficient in cross-sectional area at a critical point. This hook could have been improved by carrying the full depth ⅝ inch further along before forming the shoulder, as shown by the dotted lines.

Smallness of section around the eye was the cause of three failures, almost exactly identical, which are represented by *Fig. 5* (*b*); the pull of the train, in these cases, acted in a line nearly 2 inches above the centre-line of the draw-bar; this defect is also shown in *Fig. 7* (*k*). Two new hooks (standard pattern), which, when tested in the machine, failed at 43·75 tons and 44·70 tons, are shown respectively in *Figs. 5* (*f*) and *7* (*b*).

Fig. 7 (*h*) illustrates a clear case of faulty design in several respects. In the first place, the pulls on the hook and on the draw-bar could not have been in the same straight line even if the coupling had occupied the lower position, but the outline of the hook would not permit of this, and the link therefore took up the higher position, where it has 25 per cent. more leverage to

produce a bending moment on section A A, and in the case of section B B, instead of a straight pull, W (which could have been arranged for in the design), there has been a stress $(W + W\,l)$ where $l = 2$. This excessive stress has led to the flaw shown in the Figure, and subsequent fracture. The corners B B were also too sharp, although in this instance they did not lead to failure.

Figs. 7.



Scale, 1½ inch = 1 foot.

FAILURES IN DRAW-HOOKS.

Figs. 7, (*f*) and (*g*), are examples of broken side chain hooks. It will be noticed how much the hook of circular section has opened out before fracture, an effect which does not occur with a flat section.

γ. *Draw-bars.*—The failures of these number 818, and comprise

failures of draw-bars and pins, draw-bar cotter-boxes and cotters, the number being made up as shown in the following Table :—

TABLE VII.

Cause of Failure.	Number of Failures.			
	Draw-bar.	Draw-bar Pins.	Draw-bar Cotter-Box.	Draw-bar Cotter.
Rough usage	232	131	8	5
Flaw	111	32	7	4
Unsoundness	77	..	..	..
Light section	64	10	..	..
Coarse and bad material .	23	2	21	..
Worn	..	9	20	39
Light section and flaw .	18	..	..	..
Miscellaneous	5	..	..	..
Totals . . .	530	184	56	48

The draw-bars are now usually $1\frac{3}{4}$ inch in diameter, but those in use range between $1\frac{1}{4}$ inch in diameter and 2 inches square. They are between 3 feet and 6 feet in length, in the best practice being continuous and elastic, having an eye and pin at one end for attachment to the draw- and buffing-spring, and a screw at the other end to the cradle or mechanism for giving elasticity to the bar. In wagons in which the gear is continuous but not elastic the two ends are joined by cotters and box, *Figs. 9.* In some of the old wagons, and a few new ones for special purposes, the draw-bars are not continuous. This is apt to throw great stresses on the buffer beam and framework.

Draw-bars should be made from the same quality of iron as the hooks, giving 23 per cent. elongation in 4 inches and 23 tons per square inch ultimate stress. The draw-bar ends are forged and finished separately, and are afterwards welded on to the long plain portion. This method is adopted partly for convenience in handling, such as cutting the screw in the lathe, and also because it is found more satisfactory to forge the eye from scrap iron than to weld a collar on to the rod, "jumping up" the rod end being, of course, inadmissible.

The failures may be treated under the following headings :—

Rough Usage.—Table VII shows very clearly the extent to which draw-bars and pins suffer from this cause, the proportions being 45 per cent. and 71 per cent. respectively. The bars show a straight fracture across the fibres, with a clean crystalline surface and no reduction of area. The greater number of failures occur

in the eye, at the sides or the end, *Figs. 8*, (*a*) to (*e*). Pins usually break right across, showing a wholly crystalline fracture, and as they are an easy fit even when new, they fail by a bending rather than a shearing action. Indeed, some pins which have been at work in a worn eye bend slightly, previous to failure. The Author is of opinion that a number of pins fail from being too light for their work rather than from rough usage, although a large majority have been classed under this head merely on account of the soundness of the material in them. Rough usage discloses the weak points of the V thread adopted, as most of the failures in draw-bars caused thus, other than those through the eye, occur at the bottom of the thread just outside the nut. Round threads (as used for carriage screw-couplings) would obviate this. Cotter-boxes give way by the metal being torn off at the end of the cotter-hole, sometimes by the complete end being torn off. Cotters show the planes of shearing, often being taken out in three pieces, one in each side of the box, and the centre piece remaining in the draw-bar.

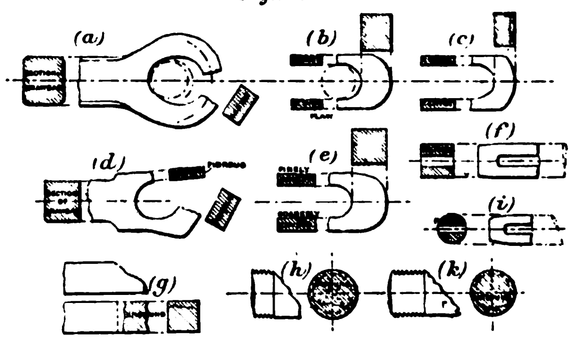
Flaws.—Undoubtedly many of these are due to fatigue of the material. In the bars themselves they occur chiefly in the eyes, and have been caused in the first instance by rough usage, which produces a stress exceeding the elastic limit, and forms a crack at the weakest point, either the end or the side, and this crack afterwards rusts and extends under service. The fact that flaws frequently accompanied light sections serves to bear this out, as the sectional area was so small that shocks must have occasioned stresses in them in excess of the elastic limit, which only produced stresses well under this limit in the rest of the gear. The fractures of the eyes broken through the end, as in *Figs. 8*, (*a*) and (*d*), are often found on examination to be old and rusty, showing that the end has been broken by a shock, and that the eye has been sufficiently strong to hold together under the ordinary stresses of daily use until it has experienced a second shock, which has bent open the sides and allowed the pin to escape. In the pins, flaws invariably show as a rusty crescent-shaped defect on one edge of the fracture, the rest of the area being finely crystalline in grain. Sometimes badly punched or square-cornered cotter-holes start cracks at their upper corners, causing fractures similar to those shown in *Figs. 8*, (*f*) and (*i*). Cotter-box flaws are the result of poor material being used.

Unsound Welds.—Ordinary cases of bad welding at either end, to the eye or to the screwed portion, constituted 15 per cent. of the failures in draw-bars. In some cases the scarf had only been

holding by a small corner, *Figs. 8*, (*h*) and (*k*). A common fault in all these draw-bar welds is the shortness of the scarf. They are sometimes little better than a butt weld.

Light Section.—In the draw-bar rods themselves this is simply a want of cross-sectional area. Thus two wagons may be next to one another, one having a draw-bar of 1½ inch in diameter, and the other one of 1⅞ inch square, a difference in area and strength of nearly 100 per cent. In draw-bar eyes (in which the greatest number of failures occur), design varies considerably, *Figs. 8*, (*a*) to (*e*). The actual stresses in an eye are very complex. It is probable that the stress at the sides is not uniform, but is more intense at the inner edge near the hole. At the end of the eye there is a bending moment, due to the load on the pin, besides the

Figs. 8.



Scale, 1½ inch = 1 foot.

FAILURES IN DRAW-BARS.

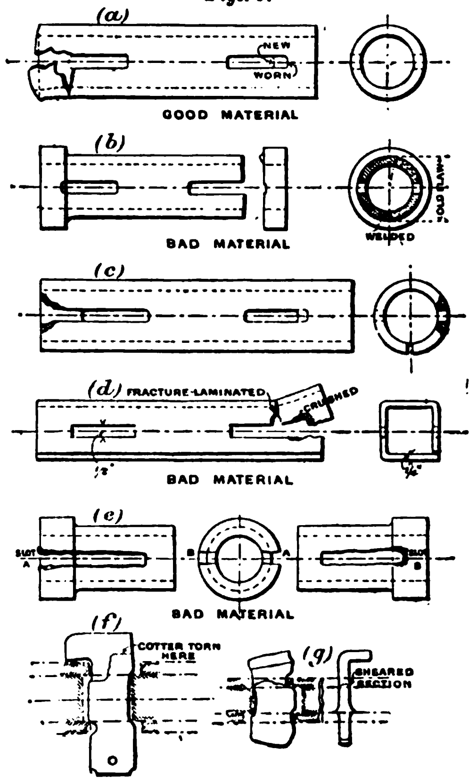
crushing action of the pin, which in time elongates the hole. The bending moment tends to burst open the back of the eye parallel to the fibres, and most failures of this kind show the fibrous texture very clearly. In designing the eye it should be noted that the sides have only to resist a tensile stress; the sectional area of the end should therefore be greater than the combined area of the sides, with an extra allowance for wear. In the standard eye the area of the end = (the area of the two sides) × 1·2. Many cases of small pins are met with. The standard diameter is 1⅜ inch, but pins of $1\frac{1}{16}$ inch in diameter are sometimes noticed. *Fig. 8*, (*i*), shows one of 1¼ inch in diameter.

Although no failures in cotter-boxes are reported as "light section," there are numerous cases which are noted as "worn," of which *Fig. 9*, (*d*) is typical. In this case the bearing area on the

cotter is much too small, the combined area of the two sides being ½ square inch, while the bearing area in the draw-bar is 1 square inch, a difference quite sufficient to explain the distortion of cotters into such outlines as those shown in *Figs. 9*, (*f*) and (*g*). The material in the square boxes is usually so bad that no other cause is required to account for their failure.

Coarse and Bad Material.—Only a small percentage of draw-bars and pins fail from this cause, one case of a laminated bar having come under notice. In the others the fracture has shown the large crystalline facets characteristic of iron which has not had much work expended on it in manufacture. Some of these failures might be due to fatigue, as the shocks of working are severe and often repeated. Cotter-boxes are usually made of plate, the cotter-holes being first punched in them, and the plate then bent (to suit the draw-bar) until the edges touch. Sometimes the edges are welded and a ring is welded on at each end. The plate employed is of a common quality, often laminated, and showing a fracture made up of alternate fibrous and crystalline layers. Recently, however, a change for the better has been noted, boxes of ⅜-inch or ½-inch steel plate of good quality being used, which have only failed through rough usage. The total number of cotter-boxes in use is not very large, and they chiefly occur in private owners' wagons, but 37½ per cent. of failures of boxes is too large for a cause of

Figs. 9.



Scale, 1½ inch = 1 foot.

FAILURES IN COTTER-BOXES.

this sort. Of the fifty-six reported, only two belonged to railway companies' wagons.

Wear.—The percentage of failures due to this cause is largest in the case of cotters, of which 81 per cent. have failed in this way. As they are not fitted accurately at first, the play in the holes provides opportunities for crushing. The same applies to cotter-boxes, in which the area to resist crushing is often too small. Some cotter-holes in the boxes thus become so badly worn that the cotters would drop out altogether were it not that the hole in the draw-bar wears so little that the head of the cotter is unable to pass through. A case in which the cotter—of good material—has worn the hole right through by a crushing action until the metal has been insufficient to resist the shearing stress and has finally given way, is illustrated in *Fig. 9* (*e*). It is of little use to replace cotters broken as a result of wear in the holes unless the box is renewed at the same time, as a cotter which fits the hole in the draw-bar is usually so much smaller than the holes in the box that the jar, caused by taking up the $\frac{1}{2}$ inch or more of play, soon breaks any cotter, however good. Indeed, the cotter shown in *Fig. 9* (*g*) was renewed twice in a journey of 80 miles, the holes being much worn. A few of the draw-bar eyes which failed through want of section at the end have been strong enough originally, but have become too slight after wearing $\frac{3}{16}$ inch or $\frac{1}{4}$ inch.

Miscellaneous.—One case each of "thread stripped" and "nut off" have been noticed, caused by the split pin at the end of the draw-bar dropping out or not having been put in at first, the nut then working back until it falls off or until it embraces so small a number of threads (usually three) that they are unable to resist the shearing stress. One case of a bent draw-bar pin was met with, caused by the nut dropping off and allowing the pin to jump up and get twisted between the draw-bar eye and the lug of the buffing spring buckle.

δ. *Springs, Buckles and Cradles.*—The Table (Table VIII)

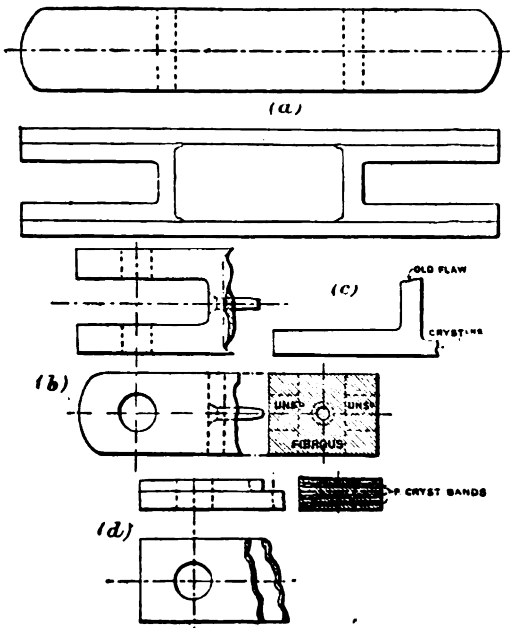
TABLE VIII.

Cause of Failure.	Spring Buckles.	Spring Cradles.	Miscellaneous.
Rough usage	57	1	3 Spiral springs.
Flaw	14	..	2 Plates.
Unsoundness	18	3	
Light section	8	..	
Bad material; laminated	4	..	
	101	4	

shows the number of various types of failure, which have been noticed and reported at the time of their occurrence; one common type of failure—broken plates, which are noticed in a large percentage of the springs when the wagons are under repair—is not included.

As will be seen from the general arrangement, *Figs. 1*, the most important springs are of the laminated type, about 5 feet 10 inches over the ends, and serve both for drawing and buffing purposes; the pull is transmitted through the hook or draw-bar to the buckle at the centre of the spring, while the buffing stresses are applied at the ends through the buffing-rods and shoes. The making of a spring involves several operations—shearing, nibbing, and tempering the plates, forging and putting on the buckles. As the majority of serious failures occur in the buckles, the best method of manufacture is indicated here. The standard buckle (*Fig. 10* (*a*)) consists of two side-plates, $\frac{5}{8}$ inch thick, and two end pieces (each comprising an end and two lugs), $\frac{3}{4}$ inch thick. The end and lugs are bent and a slight scarf is left at each corner in order to ensure a sound weld; these are welded under the steam hammer, with special swage blocks. Given good material, which can be tested in the usual manner, the only other test that can be made on the buckles, as delivered from the makers, is to try the soundness of the welding, by selecting one or two buckles out of a batch and forcing a drift into the space to be

Figs. 10.

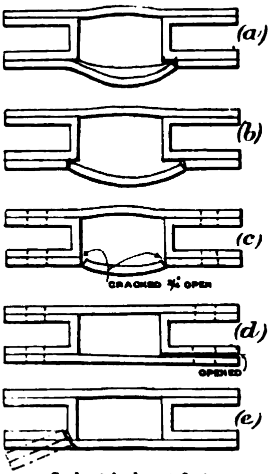


Scale, 1¼ inch = 1 foot.

FAILURES IN BUCKLES.

occupied by the spring plates; this produces the results shown in *Figs. 11*, (*a*) to (*d*). In (*a*), the weld on one side has opened out $1\frac{7}{8}$ inch at one end and $1\frac{3}{8}$ inch at the other. A similar result is shown at (*b*). As good a result as can be obtained is indicated by (*c*), the weld being perfectly sound and the wrought-iron side piece tearing through the solid in two places. The opposite extreme is illustrated by (*d*), the weld being very poor (about 40 per cent. unsound), the side plate leaving the end piece before sufficient stress has been put on even to bend the plate. The inner ends are the most difficult parts to weld soundly, and this test tries them first and most severely. Cradles are forged in two pieces (each consisting of one end washer and two half-sides), which are then welded together with a plain scarf at each side, or, as is sometimes preferred, with a plain scarf at one side and a "glut piece" welded in at the other. The causes of failure may be subdivided as before.

Figs. 11.



Scale, $\frac{1}{4}$ inch = 1 foot.

RESULTS OF BUCKLE TESTS.

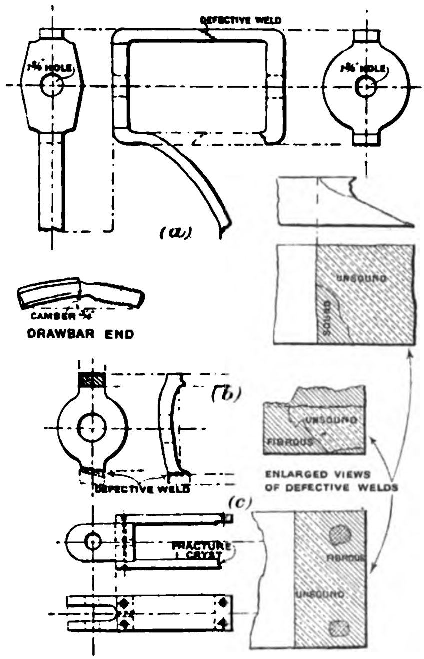
Rough Usage.—The majority of buckle failures due to this cause occur as shown in *Figs.* 10 (*d*) and 11 (*e*), the fracture commencing at the inside corner and tearing first through it and then through the side piece. The pins in these cases are usually found broken, and there is little doubt that these failures are due to the breaking of the pins rather than to any fault in the design of the buckle, as, when the pin breaks, the draw-bar end causes the broken portions to force the lugs apart, thus throwing a very severe stress on the corners of the buckle. Many spring plates are broken by rough usage; failures are assisted by burnt steel, too high carbon temper, or insufficient "letting down" after hardening. The cases of broken spiral springs were very complete, each being in about fifteen to twenty pieces, hardly a single turn remaining intact.

Flaws and Bad Material.—Flaws are found in numbers of spring plates, and are due either to the steel being too hard (either in its composition or due to careless tempering), or to faults in the manufacture of the spring, such as overheating, or water-cracking in the hardening process, etc. Springs taken out after being some years in use often display old flaws, rusted all over, in the

plates, the latter having evidently failed soon after being put into service. The flaws in buckles are found in the corners, and may have been caused by overheating preparatory to welding, with assistance, perhaps, from an extra rough shunt. Bad material, used in buckles, is shown by a laminated fracture (crystalline and gray bands alternating); this generally develops a flaw in the corner, as it will not withstand bending to form the end piece. Very few cases of poor material occur in the draw-bar cradles, as they are forged from scrap-iron, which must have a fair amount of work expended on it before the final shape is attained.

Light Section. — These cases occur in the U piece forming the sides and end; in the standard spring they are made ¾ inch thick, which gives strength to the corner, helping it to resist the bending action on it when a pin breaks; *Fig. 10* (*d*) shows a case of failure in which the thickness was only ½ inch, while the outside piece, which has chiefly a simple tensile stress to resist, was made ¾ inch thick. An extra large rivet (½ inch or over) through the centre of the buckle and spring plates seriously reduces the section at the point of maximum bending moment of the spring, and many plates fail at this point.

Figs. 12.



Scale, ¼ inch = 1 foot.
Scale for details of welds, 3 inches = 1 foot.

FAILURES IN SPRING CRADLES.

Unsoundness.—Many of the failures due to this cause might have been avoided by an alteration in the design, allowing greater facilities for thoroughly working the weld. Although very few cases of cradle failure are included in Table VIII, the Author finds from subsequent experience that the percentage is fairly correct, as out of eleven examined, seven, or 63 per cent. of the failures, were due to unsound welds. *Fig. 12* (*a*) illustrates a

typical cradle failure; the welds were ordinary scarf-welds; the detail view of the weld shows that only about 20 per cent. was sound, and after this side has given way the pull on the train has attempted to set the uninjured side and the two end washers in one straight line, until this side has given way at the corner through the solid metal; the weld at this side was of the best to resist such usage without the least sign of opening. The cradle after being damaged had evidently run for some time before ultimate failure, as the draw-bar was bent and considerably worn, as also were the holes; it was probably broken by a shock, such as starting a train. In *Fig. 12* (*b*) is shown a cradle which was so roughly used that it was bent $\frac{5}{8}$ inch at the centre; the weld is not in such a good position to resist the stresses as in the last example; neither is the method of welding so good. After the weld (60 per cent. sound) failed, the opposite side has broken through the solid; probably the whole breakage was caused by a severe shock, which bent the washer, opened the weld and broke the opposite side simultaneously. *Fig. 12* (*c*) illustrates a form of buckle which does not lend itself to sound welding so well as the standard pattern (*Fig. 10* (*a*)), and the surfaces of contact are only 3 inches by $1\frac{1}{2}$ inch at each corner, which could be doubled with advantage; only 45 per cent. of the weld that failed was sound; the weld has given way first, and has then broken the buckle through the solid metal at the opposite side. *Fig. 10* (*b*) shows another method of making a similar buckle; this weld was hopelessly bad, only about 30 per cent. being sound; the rivet, $\frac{1}{2}$ inch in diameter, has evidently assisted to hold the fabric together, a purpose for which it was never intended. Any failures of buckles made by this method, which have come under the Author's notice, have been due to very poor welding.

Fatigue causes plate springs to weaken and lose camber; after the load is taken off, the points of each plate are found to be 1 inch or 2 inches away from the back of the next plate, which they should touch when new. Tensile tests fail to show any alteration in strength or elongation. Rubber springs (used in cradles) become hard, inelastic, and cracked after long service.

BUFFING-GEAR.

This does not fail so often while at work as the draw-gear, because the action of the stress is direct and acts on few and simple parts. The ratio of failures in draw-gear to those in buffing-gear is 46·7 to 1, leaving out of account in each case the

spring and buckle failures, as the same springs serve for both draw- and buffing-gears in the standard design, *Figs. 1*. There are various other arrangements of buffing springs (such as *Figs. 1* (*e*)), but these necessitate a different type of draw-gear spring. The following Table shows the various causes of failure and the number of failures due to each:—

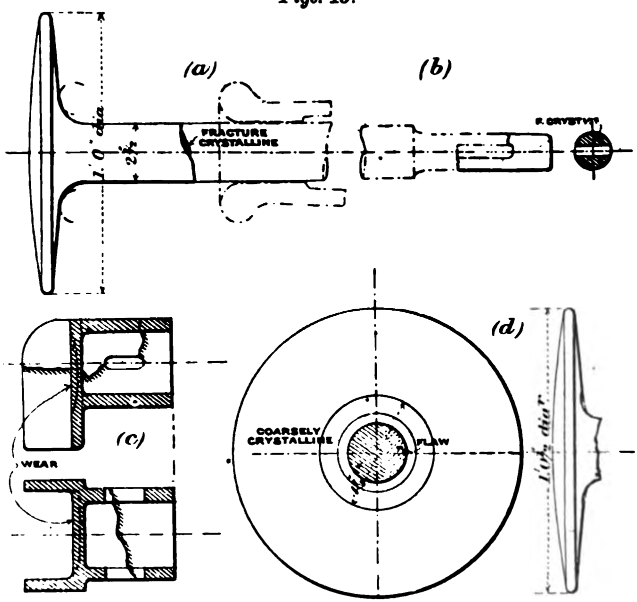
TABLE IX.

—	Heads.	Rods.	Sockets.
Rough usage	4	9	3
Flaw	1	8	1
Unsoundness	1	6	..
Light section	3	..	..
No account	8	11	2

Buffer heads and rods are made in one forging of hammered iron, from selected scrap; the sockets and shoes are castings; the springs are either plate or rubber, in the former case being the same as those mentioned in the draw-gear section; sometimes, as in the case of long trolley wagons, volute steel springs are enclosed in the buffer socket, a similar arrangement to that used in locomotive work. Failures in the heads and rods are often caused by the stress having been applied at the edge instead of the centre of the head, causing a bending moment at the point where it joins the rod and also on the rod itself just outside the buffer socket; this action soon leads to failure either at once, *Fig. 13* (*a*), or by first causing a flaw, *Fig. 13* (*d*). The heads may not meet fairly, owing to sharp curves, as in the case of shunting into sidings, where the outer edges of the heads on one side meet, or by running in the same train modern and old-fashioned low wagons, in which the sole timbers are prolonged to act as buffers, in which case the upper edges of the soles meet the buffer heads below the centre line of the buffing rods. The shoes and sockets were formerly made of cast iron, but are now being replaced by malleable iron castings, and stamped steel sockets in halves riveted together. The chief cause of breakage in sockets is rough usage, the heads being driven right home against them with violence; most buffer heads show a groove round the rod, *Fig. 13* (*d*), due to this cause, showing that it is of common occurrence. The wear of buffer sockets is never sufficient to be of any serious moment. The shoes, when made of cast iron, were continually breaking, either through the cotter holes or at the end where the spring abuts; this latter point has to bear considerable shocks,

especially when the spring loses camber, as there is then considerable play to be taken up between the end of the spring and the socket. In addition, the wear caused by the spring is very serious, *Fig. 13* (*c*), and reduces the section at a point where there are compressive and bending stresses; cases frequently occur in which a hole is worn completely through the end of the shoe, thus impeding the free movement of the end of the spring. This is a part of the wagon gear for which malleable cast iron is well suited, and its introduction has led to a considerable saving in

Figs. 13.



Scale, 1¼ inch = 1 foot.

FAILURES IN BUFFER-GEAR.

repairs. The method of testing these consists in forcing a drift, having a taper of 1 in 10, into them under the testing machine, the amount of force required to burst them being registered; this should be at least 15 tons, a tensile test piece from the same shoe giving about 25 tons per square inch ultimate stress. As the ends of the buffer rods abut on the bottom of the shoes, the cotters have to transmit no heavy pressure, and therefore do not give trouble. A typical shoe failure is represented in *Fig. 13* (*c*); this is caused by the pressure of the spring acting in a line not coincident with

the centre-line of the buffer-rod, and thus producing a bending action on the shoe. Some rods, as in *Fig. 13* (*b*), fail at the cotter hole, and it is probable that the rapid changes, both in intensity and kind of stress, cause the material of many rods to become fatigued; some of the fractures show a very coarsely crystalline structure, not accounted for by the quality of the iron.

In conclusion, the Author is indebted to Mr. Wilson Worsdell, M. Inst. C.E., Locomotive Superintendent of the North Eastern Railway, for having given him an opportunity of preparing this Paper, and to Mr. Arthur Collinson, Assoc. M. Inst. C.E., for help in its preparation.

The Paper is accompanied by eleven tracings, from which the Figures in the text have been prepared.

[APPENDIX.

APPENDIX.

Table of Tests of Material for Draw- and Buffing-Gear.

I.—Couplings 1⅜ Inch in Diameter.

Coupling. Fig. 3. Ultimate Stress.		Bar-Iron Test.		
Tons Total.	Tons per Square Inch.	Elongation per Cent. in 4 Inches.	Reduction of Area. Per Cent.	Ultimate Stress. Tons per Sq. Inch.
52·00 (3 link.)	16·89	28·75	36	22·50
56·80 (3 link.)	18·68	30·50	45	23·02
60·90 (3 link.)	19·78	30·75	40	22·50
62·30 (3 link.)	20·25	31·25	45	21·96
55·00 (5 link.)	17·87	39·00	46	21·93
60·00 (5 link.)	19·49	41·75	51	21·88
50 tons (minimum).		*35·00*	*45*	*22·00*

II.—Draw-hooks.

Finished Hook, *Fig. 5 (a).*	Forged-Iron Test.		
Breaking Weight. Total Tons.	Elongation per Cent. in 4 Inches.	Reduction of Area. Per Cent.	Ultimate Stress. Tons per Square Inch.
44·68	26·00	37	23·30
44·19	24·75	35	24·37
45·53	31·25	41	22·23
46·71	25·50	27	22·85
47·35	30·25	37	23·02
48·66 Not broken	33·00	41	22·30
	25·00	*40*	*23·00*

III.—Draw-bars.

Elongation in 4 Inches.	Reduction of Area.	Ultimate Stress.
Per Cent.	Per Cent.	Tons per Sq. Inch.
35·00	40	23·02
33·25	43	22·33
34·00	42	23·02
26 75	32	21·96
31·00	43	22·83
32·00	39	22·76
30·00	*40*	*22·00*

The North Eastern Railway specified tests are shown in italics.

IV.—Laminated Springs.

Iron for Buckles.			Spring Steel.		
Elongation in 4 Inches.	Reduction of Area.	Ultimate Stress.	Elongation in 4 Inches.	Reduction of Area.	Ultimate Stress.
Per Cent.	Per Cent.	Tons per Sq. In.	Per Cent.	Per Cent.	Tons per Sq. In.
31·75	36	21·54	21·25	42	47·35
29·75	37	21·00	20·75	49	47·40
32·75	43	21·53	22·25	47	49·70
25·75	23	23·95	14·00	25	53·57
30·00	35	23·82	13·00	28	53·60
22·00	27	24·56	10·75	17	55·83
Good tough fibrous iron.			*15*	..	*45 (minimum.)*

Buffing Gear.

Shoes.—Malleable Cast Iron.

Complete Shoe.		Test of Material.		
Bursting.		Tensile.		
	Total Tons.	Elongation per Cent. in 2 Inches.	Reduction of Area. Per Cent.	Tons per Square Inch.
Fig. 13 (c)	13·39	..	..	26·40
	12·13	..	..	25·22
	16·65	..	..	..
	17·85	2	8	26·00
Heavy pattern	21·87	..	..	..
	27·05	..	..	..

Drift. Taper 1 in 10. Tensile from burst shoe.

Cast Iron.

Tensile.	Transverse Tests (2 Inches Deep by 1 Inch Broad).				Crushing.
	Supports = 18 Inches.		Supports = 36 Inches.		
	Tons.	Deflection.	Tons.	Deflection.	
Tons per Sq. Inch.		Inch.		Inch.	Tons per Sq. Inch.
8·92	2·63	0·11	1·31	0·31	40·70
9·64	3·03	0·14	1·29	0·24	47·56
10·35	2·86	0·13	1·25	0·36	51·28
10·71	2·41	0·10	1·25	0·38	50·70
11·07	2·32	0·13	1·16	0·39	53·56
..	2·85	0·11	1·34	0·31	..
..	2·73	0·10	1·43	0·27	..
..	2·77	0·11	1·47	0·29	..
10·00	*2·7*	*0·10*	*1·35*	*0·30*	*40·00*

The North Eastern Railway specified tests are shown in italics.

(*Paper No. 3161.*)

"The Reconstruction and Widening of Public Road Bridges under Railways."

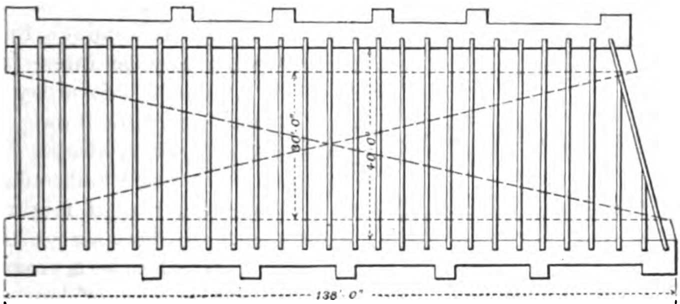
By EDWARD RICHARD ROCHE, B.A.I., Assoc. M. Inst. C.E.

IN connection with the widening works at present being carried out on the London and South Western Railway, between Waterloo Station and Clapham Junction, the reconstruction and widening of the public road bridges in the Battersea district have constituted an important item. The existing roadways have been widened to a clear span of 40 feet, and girder work has been substituted for the somewhat old-fashioned and small railway arches, the work being completed without interfering with either the railway traffic over the bridges, or the vehicular and foot traffic beneath. The methods employed may be best illustrated by a typical example, and no better type can be taken than that of Falcon Road Bridge, near Clapham Junction. To state that the railway traffic here is extraordinary is no exaggeration, and the traffic in the roadway is hardly less busy, Falcon Road being an exceptionally populous thoroughfare. Here, the width of the roadway was increased from 30 feet to 40 feet, and the 30-foot arch was replaced by girders 5 feet apart from centre to centre, with ½-inch plates between, the load being on the top booms, *Fig. 1.* This type of superstructure was necessary on account of the numerous points and crossings over the bridge.

The first operation, before commencing the excavation for the new abutments, was to place heavy timber baulks under the roads to carry them safely over the open trenches, *Fig. 2*, and it was decided to timber not more than two roads at a time, so that the necessity for slowing trains might be limited as much as possible. The work was carried on simultaneously from both ends of the bridge, and when a short length of abutment was completed the old arch was thrown for a corresponding length, and the iron-work was put in position and riveted; the sleepers and rails

were then relaid across the reconstructed portion, and traffic was resumed. This process was repeated for successive lengths, until the whole length of the bridge was reconstructed. Throwing

Fig. 1.



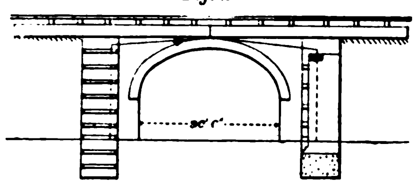
Scale, 1 inch = 40 feet.

PLAN OF FALCON ROAD BRIDGE.

the old arch and fixing the ironwork had to be undertaken between successive Saturdays and Mondays; more detailed reference will be made to this part of the work later.

In order to build the new abutments it was necessary to cut away part of the existing abutments, thereby considerably weakening them. Extra strong strutting had to be used in the trench to take the outward thrust of the arch, and as the new abutment was carried up, strutting was again inserted between the old and the new work, *Fig. 2*; the existing arch was thus always left in a safe condition. Even after cutting away the back of the old abutments for a thickness of 2 feet, there was not sufficient space to admit of building the new brickwork to the specified thickness. It was therefore necessary to leave toothing in front, and to face the abutments afterwards, when the arch had been demolished. It will be apparent that after the first length at each corner of the bridge was constructed, there was no means of access to the succeeding lengths from the ends; and as it was

Fig. 2.



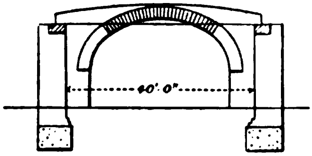
Scale, 1 inch = 40 feet.

METHOD OF RECONSTRUCTING BRIDGE.

obviously out of the question to use the permanent-way for that purpose, it became necessary to cut out arches, each about 5 feet wide and 5 feet in height, in the old abutments, for access to the work.

Proceeding to a description of the most arduous part of the work, namely, the demolition of the old arch and the fixing of the new ironwork, an account of the first Saturday to Monday's intermittent work may be interesting. At 11.30 P.M. on the Saturday the plate-layers' gang cleared away the permanent-way, every sleeper having being previously numbered and marked in order that it might be relaid exactly in the same position, as there happened to be a crossing on this part of the bridge; the ballast was cast down into the roadway, which at 1 A.M. on the Sunday was closed to the public, and 2 hours afterwards the arch was stripped and laid bare. In the meantime another gang had commenced to cut away that portion of the arch which it was necessary to demolish before the girders could be lowered on to the bed-stones, *Fig. 3.* This was proceeded with from the centre, outwards, the key being cut out first and the sides afterwards, *Fig. 4.* As a precaution against injury to the road surface, pipes, tram-lines, etc., by the falling débris, the road was covered with sleepers. It was also considered advisable to fix temporary ribs, made from old rails bent to shape, and laggings under the soffit of the adjoining portion of the arch, to prevent loose bricks from dropping from the rough and shaken face newly exposed.

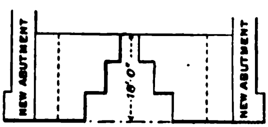
Fig. 3.



Scale, 1 inch = 40 feet.

GIRDER IN POSITION.

Fig. 4.



Scale, 1 inch = 40 feet.

METHOD OF DEMOLISHING ARCH.

In this manner, after 6 hours' work, the whole of the first 18-foot length of the arch was demolished at 7 A.M. on the Sunday. The débris measured 50 cubic yards, and there were twenty men employed, thus showing that in work of this kind three men can cut down 1 cubic yard in 48 minutes. As soon as the arch had been demolished, the ironwork gang, with their train of girders, cranes, and forges, commenced to lower the girders into position, and at 6 P.M. the girder-work

was completed. The rails and sleepers were then relaid, and at 9.30 P.M. the engines were sent on to the bridge and the girders were tested in the usual manner. Thus in less than 24 hours the first length of the reconstruction was accomplished, and on successive Saturdays and Sundays the same order of work was repeated, until the whole of the bridge was completed.

The Author is indebted to Mr. E. Andrews, M. Inst. C.E., for permission to make the foregoing communication.

The Paper is accompanied by drawings, from which the Figures in the text have been prepared.

(*Paper No. 3184.*)

"Low-Level Concrete Bridge over the Mary River, Maryborough, Queensland."

By Alfred Barton Brady, M. Inst. C.E.

The old high-level timber bridge, 1,456 feet in length, erected across the Mary River, Maryborough, in 1874, having been partially destroyed by the abnormal floods which occurred in February, 1893, thus cutting off the means of communication by road between Maryborough and Tinana and the important gold-field of Gympie, it was decided by the Queensland Government and the Maryborough Bridge Board to construct a low-level bridge of a permanent character on the downstream side of the old structure, and to take down, and remove from the site, the standing portion of the old timber bridge, the traffic meanwhile being provided for by a steam ferry.

A low-level bridge, it was considered, would serve all purposes and would be much safer during floods. It had been amply demonstrated during floods in various parts of the colony that floating logs, trees, and heavy masses of débris are not usually carried downstream in any considerable quantity until bridges built at low levels have become entirely submerged, and then all drift timber can float harmlessly over them. A low-level bridge would also necessarily be so much shorter between the banks—in this instance 843 feet shorter—and the cost of maintaining the roadway and the bridge generally would be correspondingly reduced.

After some time spent in making surveys, taking soundings and borings, and preparing and considering various schemes, the Author's design for a concrete bridge was finally approved by the Bridge Board and the Government; tenders were invited and a contract was let in September, 1894. The Author was induced to recommend a concrete bridge, as it ensures a structure of very great strength, almost everlasting in character, and the annual expenditure in maintenance is consequently reduced to a minimum.

New Bridge.—The dimensions of the new bridge, Fig. 1,

Plate 4, are:—total length, 613 feet; waterway between faces of abutments, 595 feet; width of roadway between curbs, 20 feet 8 inches; width between faces of arches, 22 feet 8 inches. The level of the roadway on the bridge is 12 feet 6 inches above high water of ordinary spring tides, when the depth of water at the bridge is 28 feet; the maximum flood-level, namely, that attained in February, 1893, is 33 feet above high water. There are eleven concrete spans, or arches, each 50 feet in the clear, carried upon ten concrete piers in the river and two abutments, Fig. 1, Plate 4. The rise of each arch is 4 feet, or $\frac{2}{25}$ of the span; the thickness of concrete at the crown of each arch is 20 inches at the centre of the roadway and 18 inches at the curbs, the thickness at the haunches along the centre line being 5 feet 8 inches, Figs. 3 and 4, Plate 4.

Abutments.—The abutments, Figs. 2, Plate 4, are constructed of Portland cement concrete, composed of 5 parts of hard stone broken to a 2-inch gauge, 2 parts of clean sharp sand, and 1 part of Portland cement, and are carried upon ironbark piles shod with 28-lb. wrought-iron shoes driven to a solid foundation, those in the Maryborough abutment to an average depth of 26½ feet, and those in the Tinana abutment to an average depth of 29 feet below low-water level, the piles being spaced 4 feet 6 inches apart, centre to centre.

Piers.—Each of the piers is constructed in two rectangular sections or columns below low-water level, arched over between low and high water and then carried up solid to the springing of the arches, Figs. 3 and 4, Plate 4. Each section of the pier foundations is 10 feet 4 inches by 5 feet 6 inches in horizontal cross-section, and all were sunk to a rock foundation, the maximum depth below high water being 55 feet 8 inches. The piers have semicircular ends above low water and are battered above the plinth at the rate of 1 in 24, the sides or faces of each pier being battered at the rate of 1 in 48, to a thickness at the impost, or string-course level, of 4 feet 6 inches, Figs. 3 and 4, Plate 4. The sections or columns, twenty in number, were sunk by means of wrought-iron caissons. The cutting lengths, 7 feet long, were formed of external bottom plates, ½ inch thick by 3 feet wide, and top plates ⅜ inch thick by 4 feet wide, with an internal pocket formed of ¼-inch plates, 3 feet 3 inches wide, having 2 inches by 2 inches by ¼-inch angles at the top, Figs. 5, Plate 4. The angle-bars at the joints of the cutting lengths were 2½ inches by 2½ inches by ⅜ inch, and acted also as stiffeners. The cutting edge was also stiffened with a flat bar, 8 inches by ⅝ inch, double riveted. The

intermediate caissons, each 4 feet in length, were formed of $\frac{1}{4}$-inch plate, jointed, stiffened and stayed with 2 inches by 2 inches by $\frac{1}{4}$-inch angle-bars throughout, Figs. 6, Plate 4, and were left in place on completion of the work below low-water level. The caissons were designed to be of the least expensive construction possible, all smith-work or forging of angles being avoided, except in the cutting lengths, where the corners were welded. In all other lengths of the caissons, the angles were cut off square, the corners being formed with stiffening pieces of 2 inches by $\frac{1}{2}$-inch flat iron, and the joints were made up with pine-wood filling. Although this plan was adopted to cheapen the cost of manufacture, it is questionable whether the extra cost of making a superior joint at the corners of the caissons by bending the angle-bars would not have been more satisfactory in the end, as the slight amount of leakage encountered in sinking the piers, at no time exceeding 300 gallons per hour, which evidently came through at the corners, might have been entirely avoided. The slight countersink left in punching the plates was found to be sufficient to hold the plates together, the rivets being simply "nobbled," and the work was practically flush-riveted on the outside, without the necessity for any countersinking of the holes in the plates.

The method adopted in sinking the piers was the following:—A temporary staging of piling, securely braced, was prepared on the site of each pier, Figs. 9, Plate 4; the bottom- or cutting-length of each caisson was slung to four wrought-iron rods, 2 inches in diameter, screwed $\frac{3}{4}$-inch pitch for 10 feet of their length, and operated by nuts with cross bars having arms of 3 feet 9 inches in length, and provided with anti-friction rings underneath. Cement concrete, gauged 5, 2 and 1, was then carefully packed into the pockets and brought up to the top of the caissons, the interior cavity being formed by removable panels of $1\frac{1}{2}$-inch rough pine, strutted as shown in Figs. 5, Plate 4. The first and second lengths of the intermediate caissons were then bolted on to the top of the cutting length, the joints being made with a chunam of coal-tar and quicklime, and the concrete lining was continued to the top. The caissons were then lowered by "fleeting" the screw hangers, for which purpose strong clamps (*a*), Figs. 9, Plate 4, were provided, additional caissons being fixed and the concrete lining being continued until the weight was taken on the bed of the river, when divers released the hangers by driving out the bolts which secured them to the cutting edge. Sinking then proceeded in the ordinary way by dredging where practicable, but the bulk of the excavation proved to be a tenacious and compact mixture of

sand, gravel and clay, with small shells, quite unsuitable for dredging, and removable only by divers. On reaching the rock, the weight of the column, amounting to 60 tons, was again taken on the screws, the suspending rods being transferred to the inside of the column, and a length of each rod being built into the concrete for suspending the column, Figs. 9, Plate 4. The surface was then levelled to a fixed depth gauged below the cutting edge by divers, and the column was finally lowered into position upon bags of fine concrete laid carefully under the cutting edges. Into these the caissons bedded themselves, forming a tight joint to exclude leakage when filling in the concrete core within the column.

The shaft was then sealed by the deposition of concrete through the water in self-releasing skips up to about 10 feet below the bed of the river at the pier. The concrete about the cutting edge, gauged 4, $1\frac{1}{2}$ and 1, was laid by a diver and carefully packed round the bags to a depth of 4 feet. The remainder of the seal was gauged 5, 2 and 1. After allowing the core to set for 2 or 3 days, or longer if convenient, the water in the shaft was removed by a canvas baler worked from a steam winch. The baler was made of No. 1 canvas, and measured 2 feet 4 inches in diameter, and 4 feet in depth, being provided with strong hoops of $1\frac{3}{4}$-inch round iron at the top and bottom, covered with leather to prevent chafing, and discharged on an average about 3,000 gallons, or about 35 lifts, per hour. The remainder of the concrete core was then laid, carefully packed and rammed, in the dry, to a level of about 8 feet below the full height of the concrete casing, thus forming a key for the upper portion of the concrete pier, Figs. 7, Plate 4.

Some leakage had to be contended with in getting in this portion of the work; the amount, however, was not considerable, averaging between 200 gallons and 300 gallons per hour. By mixing and laying with two full gangs of men, with separate steam derricks to each gang for lowering the concrete, the core was got in with sufficient rapidity to enable the packers to keep well ahead of the leakage, and so prevent the water coming through the surface of the concrete. In one or two instances, when through mismanagement this did occur, considerable difficulty was experienced in removing the water, which accumulated without disturbing the cement. To avoid such a contingency, the resident engineer had a sump formed of ordinary drainage tiles, 10 inches by 6 inches, of horseshoe shape, laid in the corner of each shaft as the core was brought up, and into this the suction-pipe of a Goold semi-rotary pump was inserted; by this means the

level of the water was kept at any time below that at which the concrete was being laid, without disturbing the cement or interfering with the packers. This sump was carried up to the level of the plinth and was afterwards filled in solid with concrete. The top of each column, forming the plinth of the pier, was laid with 4, 1½ and 1 concrete in temporary iron caissons, similar to the intermediate lengths of the permanent caissons, but having all the angles fixed externally. These temporary caissons were carried up to above high-water mark and were supported by timber shores, Figs. 9, Plate 4. The shores were arranged to be easily knocked out and removed as the concrete reached the top of the plinth of the pier. To provide for any overturning action resulting from the flood pressure upon the face of the bridge producing a tensional stress in the upstream columns of the piers, a railway rail, Vignoles pattern, weighing 60 lbs. per yard, and 20 feet in length, with suitable cross bars attached, was built into the concrete, Fig. 4, Plate 4.

The matrix for constructing the piers above plinth level was then formed, having framed moulds for the circular ends and for the arch connecting the sections or columns, and 1½-inch pine boards supported on studding for the intermediate flat surfaces, all properly stayed against the false works used in sinking the columns of the piers. The work of laying the concrete, gauged 5, 2, and 1, was commenced immediately the falling tide had left the surface at the plinth level. These surfaces had been previously thoroughly cleaned and picked over, and were well grouted with 1 to 1 compo, to receive the upper concrete work, the first few gauges deposited being made richer in cement to secure perfect adhesion. The packing of the concrete was carried on well in advance of the rising tide, to the height of the string course, which was subsequently laid of 4, 1½ and 1 concrete in framed moulds. The whole of the concrete in the piers was deposited in self-discharging skips, Figs. 6, Plate 4, worked from a punt on either side of the pier. The temporary wrought-iron caissons, from the river-bed up to low-water level, were by an arrangement with the contractors, left as a permanent protection to the concrete piers. The average pressure upon the foundations, making due allowance for friction and buoyancy, amounts to 4·14 tons per square foot.

Superstructure.—The concrete in the arches or superstructure of the bridge is composed of 4 parts of broken hardstone of 2-inch gauge, 1½ part clean sharp river sand, and 1 part of Portland cement. The segmental arches are strengthened by means of a

continuous framework formed of steel railway rails, Vignoles pattern, weighing 41½ lbs. per linear yard, spaced 2 feet apart in the arching, Figs. 2, 3, and 4, Plate 4. There are eleven skeleton frames in all, each consisting of two members only, viz., a horizontal top member, continuous for the entire length of the bridge, and a curved or segmental lower member, following the curvature of the arch in each span, Fig. 3, Plate 4. The frames are bolted to cast-iron chairs or bed-plates on each pier and abutment, and on the latter the chairs are well anchored down to the concrete by long bolts and plates, Figs. 8, Plate 4. There are two cross ties to the framing in each span and one over each pier, each tie being 2½ inches by 2½ inches by ⅜-inch iron angle-bar riveted to the flange of the upper member of the skeleton framing, Fig. 3, Plate 4, chiefly for the purpose of stiffening and giving lateral support to the framing during the deposition and ramming of concrete in the arches. The concrete was laid on wood centering, and the steel skeleton framing was completely embedded. The whole surface of concrete exposed to view above low-water level, including soffits of arches, was floated to form a uniform surface, with 1 part of Portland cement to 2 parts of sand laid on in two thicknesses, and finished to not less than ⅝-inch thick; the whole then received a coat of cement-wash, composed of 6 parts of cement to 1 part of sand, mixed fluid in buckets close to where it was required and used immediately afterwards.

In constructing the arches forming the superstructure of the bridge, a considerable amount of forethought had to be exercised to ensure the joints being placed in the positions least detrimental to the ultimate strength of the structure, considered in relation to the flood stresses, as well as to those resulting from the maximum superimposed load, and also to secure the deposition of the greatest quantity of concrete practicable during daylight—which was not more than 11 hours—as the contractor's arrangements did not admit of continuing work through the night. With this object in view, it was decided to lay a half width of a complete span each day, and this arrangement was adhered to, the whole superstructure being laid in 22 days, with the exception of the parapets, which were built subsequently. To assist the transverse joints between contiguous arches, two cavities, each 4 feet by 2 feet 6 inches, were left along the tops of the piers and extending the full depth of the haunches of the arch; these cavities were afterwards filled in with a richer concrete gauged 3, 1½ and 1, forming keys which materially assisted the joint to withstand flood-stresses.

The false works for laying the arches were of pine timber throughout, and consisted of six ribs, 4 inches thick, in the width of the arch, supported on capsills carried on three piles driven into the river-bed at the centre of each span, the outer ends being carried on the staging of the piers. Each rib was 2 feet deep at the centre and 1 foot at the ends, and was formed of two flitches securely bolted together with ⅝-inch bolts. The ribs were laid with 1½-inch pine planking, wedged at the ends to the required levels, and afterwards securely strutted on to piling. The mould was then completed by the erection of the sides, of 1¼-inch boarding on studding, strutted by longitudinals from the piers to the centre capsills, Figs. 7, Plate 4. The whole of the concrete for the arches was gauged 4, 1½ and 1; it was mixed on a large platform, laid on the abutment on the Maryborough side, the stone being carted from a heap 400 yards away and tipped direct into the gauge boxes, and the sand being wheeled from a heap close at hand.

The mixed concrete was conveyed from the platform to the packers in side-delivery tip-wagons running on a temporary tram-road, from which it was discharged on to concrete boards and shovelled therefrom into the work, being well cut in with spades, and rammed solid, a special form of rammer being provided for packing under the bottom rails of the skeleton framing. The concrete was mixed moderately wet, it being found that any excess of water drained off readily through the cleading of the mould, without carrying away cement, the water which escaped being perfectly clear and limpid, whilst the concrete laid better together and could be rammed without difficulty.

As it was thought probable that during floods an upward thrust might be brought to bear upon the arches on the upstream side by trunks of trees or logs of timber becoming jammed under them, a nest of six steel rods, each ⅞-inch in diameter, was built into the concrete across the full span of each arch and parapet curb, along the upstream side of the bridge only, to resist the stresses induced by such an upward thrust, Fig. 10, Plate 4. Steel rail dowels were also used at intervals to connect the concrete parapet curbing to the arching.

The average number of men employed in forming the arches was as follows:—Seventeen labourers filling gauges and mixing concrete, six labourers filling trucks and running them to four packers and rammers; also four labourers loading stone and sand, six horses and drays with drivers, and one carpenter; or forty men

in all, who mixed and laid, on an average, 11 cubic yards of concrete per hour.

Stone.—The only cut stone in the bridge is the sandstone coping to the blockings of the parapets at each end of the bridge, the bedstones to the lamp pillars, and the porphyry margin stones to the gully gratings, Figs. 2, Plate 4.

Roadway.—The roadway on the bridge was formed of iron-bark block paving, 5 inches deep, sawn from 9-inch by 3-inch planks. The blocks were coated with boiling tar and were laid with close joints directly on the surface of the concrete superstructure, which was finished with a camber or rise of 2 inches along the centre of the roadway for drainage. The blocks were cut and stacked for seasoning six months before being laid, and after laying, the joints were completely filled and made watertight with a boiling mixture of asphaltum coal tar, and clean sharp grit or river sand. When completed, the whole surface of the wood paving received a thorough coating of well-boiled tar, and was afterwards covered with a layer of sharp sand. Four rows of blocks were laid longitudinally against the curbs on either side of the bridge, the paving between the longitudinal rows being laid transversely. A space or seam, 1½ inch wide, was left next the curbs, and was filled with mastic to allow for the expansion of the blocks in wet weather. A disastrous flood, however, which occurred in January 1898, did so much damage to the roadway, washing off about two-thirds of the wood blocking, and the whole of the metalling on the approaches, that it was decided to remove the remaining portion of the wood paving, and to lay the entire length of the bridge and its approaches, a total length of 1,071 feet, with tarred metalling, composed of two parts of hard blue metal broken to a 2-inch gauge, two parts to a 1-inch gauge, and one part of blue metal screenings or chippings to pass through a ¼-inch mesh, the whole thoroughly dried by heat and then well mixed with boiling coal-tar and stacked to allow the superfluous tar to run off, after which it was spread uniformly, to an average depth of 6 inches, well punned or rammed, brought to an even surface, and then well rolled with a 5-ton roller until thoroughly consolidated, and formed to the proper convexity.

The entire area of tarred metalling was afterwards coated uniformly with fine grit sifted from the blue metal screenings. The coal-tar was kept continually boiling for at least 3 hours before being mixed with the metal or screenings, and tarred metalling was prepared and laid down during fine weather only. This work was completed satisfactorily in November 1898. The

surface drainage from the roadway on the bridge is provided for by two gully chambers every 54 feet in the length of the bridge, formed in the concrete of each span, covered with wrought-iron surface gratings in cast-iron frames, protected with hardstone margins, and having outlet pipes, 4 inches in diameter, through the arches, discharging directly into the river, Fig. 1, Plate 4.

Parapets.—The handrailing of the bridge consists of removable wrought-iron stanchions fitted with turned ends into galvanised cast-iron sockets, set in the concrete curbs. Through the forged stanchions pass three rails formed of gas tubing, screwed together at the joints, the two upper tubes being 1¼-inch bore and the lower tube ¾-inch bore. The parapets are made in sections, four to each span, or 13 feet 6 inches in length, having three stanchions in each, for convenience of removal, and with special semicircular sections on the four intermediate escapes over the piers. It was demonstrated by the resident engineer before the opening of the bridge, that, with the aid of three men, the entire handrailing could be removed in sections, replaced and keyed up again and fixed perfectly rigid in 3 hours; thus showing that, in the case of a sudden rise in the river, no fear need be entertained for the security of the handrailing.

The lighting of the bridge is provided for by four gas-lamps fixed on the upstream side, the end lamps having three lanterns carried on cast-iron standards, and the two intermediate lamps having one lantern each, carried on 3 inches by 3 inches by ⅜-inch arched angle-bar standards. The lamps are fixed with special connections, so as to be easily removed in the wet season to leave the surface of the bridge clear for the passage of flood waters over it. Several floods occurred during the construction of the bridge, that on the 17th February, 1896, rising to a level of 85·39 feet, or within 14·46 feet of the great flood in 1893; and since the completion of the bridge two heavy floods have passed over it, doing no damage whatever to the structure of the bridge, which stood the severe tests admirably, the only damage sustained being to the roadway as already described.

The total cost of the bridge and approaches, including engineering and supervision, amounted to £25,000. The first contractor having failed financially in May, 1895, before much work was done, a second contract for the construction of the bridge had to be let; the successful tenderers were Messrs. McArdle and Thompson of Brisbane, who signed their contract on 26th July 1895, the time allowed for the completion of the work being 15 months. The contractors completed their work within contract time in a

highly creditable manner; the bridge being novel in character, and the river subject to frequent floods, the work was not carried through without some difficulties, which, however, were successfully overcome.

The bridge was formally opened for traffic with some ceremony on the 30th October, 1896, by the Hon. David Hay Dalrymple, M.L.A., Minister for Public Works, in the presence of a large and representative assembly of the public, and the structure was named the Lamington bridge, in honour of His Excellency the Right Hon. Baron Lamington, K.C.M.G., Governor of Queensland.

In concluding this Paper, the Author has much pleasure in acknowledging the able assistance rendered by the Resident Engineer on the works, Mr. Alfred J. Goldsmith, M. Inst. C.E., to whose fertility of resource, engineering skill, painstaking and vigilance, extending over a period of 2 years, must be attributed in a large measure the successful completion of the structure, the first of its kind in Australia.

The Paper is accompanied by four drawings and four photographs, from a selection of which Plate 4 has been prepared.

APPENDIX.

The following are the prices paid for the different descriptions of work in the bridge and approaches :—

	£	s.	d.	
Excavation in abutment foundations	0	3	0	per cubic yard.
" " pier foundations (including cost of staging[1] and wrought-iron caissons, also levelling surface of rock bottom)	5	0	0	" " "
Ironbark piles for abutment foundations	0	3	6	" linear foot.
Sawn hardwood in capsills and planking	0	3	6	" cubic "
Wrought iron in pile shoes and spikes	0	0	4	" lb.
Cement concrete (5 stone, 2 sand, and 1 cement) in abutments	1	15	0	" cubic yard.
Cement concrete in piers (5, 2, and 1)	2	3	0	" " "
" " " imposts (4, 1½, and 1)	2	7	0	" " "
" " " arches (4, 1½, and 1)	3	1	0	" " "
" " " parapets, copings, &c. (4, 1½, and 1)	2	10	0	" " "
Rubble stone backing to abutments	0	4	0	" " "
Freestone coping and lamp bases	0	9	0	" " foot.
Cast-iron chairs to skeleton framing	1	0	0	" cwt.
Wrought iron in bolts, nuts, &c.	0	0	5	" lb.
" " " angles and rivets	1	0	0	" cwt.
" gully-frames, gratings, cramps, dowels, &c.	3	0	0	" "
Steel railway rails to skeleton framing, straight	9	0	0	" ton.
Steel railway rails to skeleton framing, curved and forged	14	0	0	" "
Steel in fish-plates, and covers to all connections	30	0	0	" "
Hardwood block paving on bridge	0	14	0	" square yard.
Excavation for approaches	0	2	0	" cubic "
Stone pitching 7 inches deep on embankments	0	4	0	" superficial yard.
Metalling on roadways of approaches	0	9	0	" cubic yard.
Wages of labourers	0	0	9	" hour.

[1] The cost of staging was equal to about 8s. per cubic yard of excavation; the actual cost of the wrought-iron caissons, including conveyance from the banks of the river, fixing and jointing, and cost of lowering gear, was equal to about £2 16s. 3d. per cubic yard of excavation.

QUANTITIES OF PRINCIPAL ITEMS IN BRIDGE.

Excavation in foundations of piers and abutments .	1,250 cubic yards.
Piles in abutment foundations	565 linear feet.
Wrought iron in pile shoes	532 lbs.
Portland-cement concrete in bridge	4,270 cubic yards.
Cast iron in chairs to skeleton framing	3·53 tons.
Steel and ironwork in skeleton framing to superstructure	88·11 „
Wrought iron in anchor bolts, plates, gullies, sockets, cramps, dowels, &c.	2·63 „

(*Paper No. 3190.*)

"The Effects of the Earthquake in 1897 on the Shaistaganj Division of the Assam-Bengal Railway."

By Francis Philip Anderson, M. Inst. C.E.

The Southern Section of the Assam-Bengal metre-gauge railway runs in a north-westerly direction from Chittagong to Laksam, a distance of 81 miles, thence in a northerly direction to Akhaura, at 125 miles, and thence in a north-easterly direction to Badarpur, at 252 miles, to which point the main line was opened in June 1897. The Shaistaganj division at that date began at the 133rd mile, and ended at the 229th mile, a little short of the northern terminus. Parallel to, and eastward of the Shaistaganj division of the railway is a range of mountains, the drainage area of which is crossed by the railway. This section of the railway nowhere attains any considerable altitude; the highest point is only 146·50 feet, and the lowest 33·00 feet above mean sea-level, the line for the most part traversing an alluvial plain. There are, however, two points where it cuts through two ranges of low hills covered with dense jungle. These hills for the most part consist of sand, resting on clay, the sand in some places being 60 feet deep, and the railway cuttings being sometimes 80 feet deep and even more.

The alluvial plain is studded with clusters of hills, called "tilas" by the inhabitants. A tila may be only 2 feet or 3 feet out of the plain; on the other hand, some attain a general altitude of 50 feet. They generally consist of moorum, covered with sand, and are used as homestead land; where not so used they are covered with dense jungle. The land between the tilas is cultivated, except where it consists of bog, often of great depth. Crossing these bogs constituted the chief difficulty in constructing this portion of the railway, and no formidable engineering difficulty was encountered. The largest river, the Manu, is crossed by four spans of 60-foot and one of 40-foot girders, and, to accommodate the Manu spills, an aggregate waterway of about 1,000 feet has been allowed.

The earthquake recorded in this Paper occurred at 4.30 (Madras time) in the afternoon of the 12th June, 1897. It lasted about 3½ minutes, the oscillations being from east to west at the rate of ten a second. Speaking generally, the earthquake did little or no damage to the railway where it runs through the hills and tilas. The wing-walls of a few bridges were cracked, but not destructively, the earthwork and permanent way being left uninjured. On the plain, however, and between the tilas, the damage was enormous. The damage on the plain will be described more in detail further on. Between the tilas, if the bank crossed a bog, it was shaken down into it. At one place, where the line crosses a bog, known as the Dulcherra, at least 30 feet deep and about 1,000 feet wide, and where the filling of bank across the bog had proved very troublesome, the earthquake shook the bank down into the bog, and left it with almost as much to fill again as when work on it was begun.

The earthquake, in crossing the plains, seems to have acted in a wave-like manner. Where the surface of the plain is cut by a river or stream, it left the river bank in a succession of steps or ripples. The waterway was invariably reduced, though the impulse seemed to reach the river sometimes from the left bank and sometimes from the right. At the Markhal, at 212 miles, it seems to have come from both banks, the piers all leaning towards the centre of the river. At the Khawai the impulse was from the right bank, and at the Dhulai, 30 miles north, it was from the left. The destructive energy of the earthquake was nowhere more manifest than near Shaistaganj, although so far from the focus of the disturbance. Here the line crosses an alluvial plain drained by the Khawai river, and the earthquake effect may be considered typical of such convulsions, and worthy of study in detail. Near the Khawai, the bank opened out in great fissures; these run underneath, parallel to and across the line of railway, and afford no safe indication of the line of force of the earthquake; on the ordinary ground-level, mud and sand welled out of the fissures and did much damage to the crops. One of the most extraordinary effects of the earthquake occurred at a point 1½ mile east of the Khawai. Here the whole road, bank, rails, and bridges, for a length of over a mile, was shifted about 6 feet to 8 feet northwards. At Daragaon 5 miles east of Shaistaganj, the west end of the station-yard, for its whole width of 4 chains, sank 2 feet to 3 feet into the ground; as the ground sank, water welled up, and nothing could be more terrifying to behold than the manner in which the very ground seemed to dissolve in the welling water.

It is worth noting that the ground on which the bank on this part of the line was super-imposed, sank under the weight of the bank (this was the case almost everywhere that the line is in alluvium), the water standing at the toe of the slope to a depth of several inches. On the rails and sleepers the effect was as terrible as on the bank; in some places the rails parted at the joints, leaving gaps, varying in length between a few inches and as much as 2 feet 3 inches in one case; in others, the rails buckled right across the road; within 4 miles of the Khawai there were seven such kinks.

The bridges suffered chiefly from the narrowing of the waterway, causing butting of the girders, and thereby pushing off the ballast walls, but in many cases the piers were tilted so that they no longer supported the girders, and these were left suspended only by the rails. The type of bridge which suffered most was the ordinary splayed wing-wall type; box abutments suffered very little, comparatively speaking, and there was no case of a simple structure like a pier showing even a crack, though many were tilted, some in one direction and others in the opposite. As already mentioned, bridges founded on non-alluvial formations suffered little or no harm; in addition, it is interesting to note how certain bridges, founded in alluvial clay, escaped scatheless; one in particular, a 12-foot girder-bridge of the splayed wing-wall type, situated in the midst of the area of maximum disturbance, $\frac{1}{4}$-mile north of the Khawai and $\frac{1}{2}$-mile south of the scene of the total displacement of bank rails, bridges, and centre line, showed not even a crack. It not only escaped harm from the great convulsion of the 12th June, but also from the lesser but still very severe earthquakes which succeeded it.

To restore the line to a condition fit for running would have been easier had the earthquake occurred in any of the earlier months of the year; the ordinary labour in Sylhet, the district through which this part of the railway runs, is all imported from countries west of Calcutta, and it is the custom of the labourers to return to their homes at the beginning of the rains. The only available labour was the permanent-way staff, assisted by a few men picked up locally. Fortunately, three trains, used for leading ballast, were at work in the division; when the earthquake occurred two of these were at work in the hills, and were available for service at once, while the third was standing delivering a load on a bank near the Manu River. The whole train, engine and wagons, subsided with the bank into the ground, but at this spot the shock was not severe, and the train was got out and into working order within a week.

Each difficulty was coped with on its merits; the rails were raised, and, if the ground had sunk, earth was led to the site by train. Where the rails were kinked they were removed, and new pieces were put in, whole rails being obviously impossible; on the bridges, the girders were put in line, and if the bearing surface was disturbed, they were packed with wooden chocks. When the shoe plate was insufficiently supported by a pier, sleeper stacks were built beneath to support the girder. At the Khawai, arrangements were made for a diversion, with a temporary timber bridge across the river. In the meantime, passengers were to walk across the bridge, while the train was to be pushed across slowly to the charge of another engine on the further side.

By these means traffic was resumed on the 1st August, seven weeks after the earthquake; the temporary arrangements described in the foregoing proved adequate for the traffic until after the rains, when permanent repairs were begun.

The Paper is accompanied by an album of photographs and a seismogram illustrative of the great earthquake.

(*Paper No. 3091.*)

Tropical Sanitation, with Special Reference to Hong Kong.

By Robert Gervase Alford, M. Inst. C.E.

The town of Hong Kong lines the southern shore of its magnificent harbour for a distance of 3½ miles, and extends backwards ¾ mile, attaining an altitude of about 500 feet, on the slope of a range of hills which rise 1,800 feet above the sea. The island is a mass of highly felspathic granite in all stages of disintegration, and has an area of about 26 square miles. The old drains, designed by the earlier British officials, consisted mainly of the natural mountain water-courses, built up with granite sides and invert, and covered by granite slabs. In many cases they were square in section, and they were of sufficient size to carry off the storm-waters from the town and from the hills above. Hand-carriage of sewage was universal, and water-closets were almost unknown, except in a few clubs and hotels situated near the sea. The sea-ward portion of the town has been largely reclaimed, and is being extended to a distance of about ¼ mile from the foot of the rising-ground; the extension, however, being flat, gives no natural fall to the sewers.

The following is the estimated population in the middle of 1899:—

Non-Chinese population		8,915
Chinese population—		
City of Victoria, including Peak and Stone-cutters' Island	168,260	
Villages of Hong Kong and Kowloon	40,530	
Floating population	34,700	
Total Chinese population		243,490
Army		3,520
Navy		3,385
Total population of the colony		259,310

In general, the Europeans live above, and the natives below, the 300-feet level; in the centre of the town, however, the cantonments and Naval yard extend from the hill to the shore, and to the

west of these is the large business portion, where between an altitude of 300 feet and the sea, for a cross distance of rather less than ½ mile, Chinese and Westerns alike congregate during the day, but where few of the latter remain at night, and here many defects in sewerage have been found. The mean sea level is 3·69 feet above ordnance datum,[1] and, the discharge inverts of the new drains being slightly above this height, the tide fills the sewers to a depth of 3 feet for a distance of nearly ¼ mile from the extended shore, driving back the sewage and preventing free discharge for many hours daily. This constitutes a serious obstacle to efficient drainage, but the lengths of the sewers would be thought inconsiderable in a European town. The exigencies of harbour reclamation also for many years temporarily affected the sanitary state of the town by stopping old sewer mouths. The harbour, which is simply a strait separating the island from the mainland, is continually swept by a strong tidal current, during both ebb and flood.

Hong Kong,[2] at the time of settlement, was considered an extremely unhealthy place, but it has been found that the mortality is only high in certain seasons. It is not free from a certain malaria, and the change from the heat and rain of summer (May to October) to the refreshing temperature of the cool, dry season tends to produce disease of the kidneys, etc., but the winter climate has been well described as equal to that of the best seasons in the Riviera. During the years 1871–75 the mean temperature was 73° in the shade, the range being 56° to 84°, taking the mean readings for the months, with a maximum of about 95°. Occasionally the thermometer registers below 40°, and on the 26th February, 1876, when extreme cold was experienced, water was frozen to the thickness of ¼ inch. The annual rainfall was 99·24 inches in 1871, and 83·43 inches in 1875, and the average may be taken as 85 inches, of which 70 inches falls between May and September. The town water-consumption is 90 million gallons monthly when constant, and 56 million gallons when intermittent, as for the 8 weeks from April 1899. Public sanitary improvements were first contemplated in 1874, when the Author took part in the inquiry. The native parts of the town were found to be in a filthy state, and reforms, principally intended to prevent over-crowding and the occupation of cellars as living

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[1] Ordnance datum in this colony is mean low-water level.

[2] This description of the climate is taken in part from the *Encyclopædia Britannica*.

rooms, and to introduce more light and air to native dwellings, were urgently pleaded for. It was desired to call attention to existing abuses rather than to propose any new system of drainage, this being beyond the scope of the instructions received.

In a report[1] on the sewerage of the high-level district of Victoria, published in 1890, the following recommendations were made. First, that the high-level district (mainly inhabited by Europeans, and above the 300-feet contour) should be treated on different lines and as a separate division of the town, and should discharge by an intercepting sewer at a distant point, not directly below the collecting area. Secondly, that the sewage from the lower zone, with the rain which falls upon it, should be conveyed to the sea by small pipe drains; and, third, that the storm-waters from the hill-sides above should be separately conveyed through the lower district to the sea. It was urged in the report that by these means, when the system of self-cleansing sewers was complete, the sewage would be delivered into the harbour before putrefaction had commenced, assuming the house-drains to be in order. It was added, however, that the universal introduction of the water-carriage system was not anticipated, as it was believed that the population generally was not ready for it, notwithstanding its superiority to any other. When the proposed works were complete there would be no objection to the use of water-closets by those who desired them, provided always that proper appliances for flushing were used in connection with them. (This did not refer to public flushing, which should be unnecessary in "self-cleansing" sewers.) The introduction of water-closets would be a great boon to the European community, for as the prosperity of the community increased there would be more and more difficulty in having hand-removal properly carried out. If water-closets were largely introduced in European houses their use might spread to the Chinese also. If such a tendency did show itself it should not be resisted. The remedy proposed for the principal inconveniences experienced in connection with sewers consisted mainly in good house-drains, properly made and properly used. The Government might assist the householder in obtaining good house-drains, but the people themselves had the prevention of nuisances mainly in their own hands. If they would take care of their house-drains, the sewers

[1] "The Sewerage of the High-level District," and "The Drainage of the Lower Western and Central Districts;" addressed to the Acting Colonial Secretary, and published 5th June 1890, and 23rd June 1890, respectively.

would look after themselves. Unless the public generally co-operated with the Government in sanitation by looking after the interior arrangements of their dwellings, by insisting on the drains being well constructed and properly maintained, all expenditure on sewers would be, if not useless, much reduced in value as affecting the public health.

Upon the lines advocated in this report, action was taken, and the construction of sewers on the "separate system" was commenced. The finances of the colony do not appear to have allowed of any very rapid execution of the scheme as a whole, and although main lines of sewers were carefully constructed, the connection of the house-drains seems to have been only commenced when the Bubonic plague made its appearance in 1894. The outbreak took place early in May, and the total number of deaths up to the 16th June was 1,900. On the 22nd June the deaths numbered 34, on the following day 35, and on the 24th June 39, and it was not till about the 26th July that the daily number showed much abatement, when it fell to 5. The average from early in May onwards was 34 per day, till three thousand people had been carried off, and fifty-six days after the plague commenced it was estimated that eighty thousand persons had fled the colony.

It is unnecessary to recall the details of this distressing time; business was disorganised, panic prevailed amongst the natives, and it became necessary to depopulate the portion of the town (higher Tai-ping-shan) principally attacked, and to wall up the streets and lanes, before the outbreak could be checked. This area was afterwards resumed by the Government, and the houses (mostly three-storied tenements) were razed to the ground. The district has since been laid out afresh, but up to the present time it has been only partially taken up and built upon. The plague returned in 1896 and again in 1898 and 1899, in the summer, fortunately with less violence.

The Bubonic plague, and the causes which lead to it, form an interesting study. That it is a "filth disease," though not of the typhoid nature, there can be no doubt, and the Japanese claim the discovery of its microbe, while Professor Koch's recent report further elucidates its medical aspects. It is endemic in Western China, and the native theory is that it is caused by emanations from cracks in the ground after drought. The civilized cities of Hong Kong and Bombay seem to have been affected equally with the most insanitary towns under native management. It is remarkable that during the first fifty years of the settlement of Europeans in Hong Kong, it was never visited

by the plague. There never was a native-built town on the site, a few fishermen's huts alone existing prior to 1841. It is not supposed that the plague was ever warded off under the conditions found existing in 1874; it is believed never to have threatened the place, though known by report in neighbouring provinces. The interesting question is not whether the Bubonic plague originated in one place or another, for it appears to have been always a scourge, more or less devastating Eastern countries, but rather, why was it not repelled at the outset when it attacked civilization? There can be, unfortunately, no doubt of the connection of the plague with sanitation; the President of the Hong Kong Sanitary Board expressed the opinion in 1894 that dirt had been the chief cause of the plague.

It may be urged that the sanitary reforms were then incomplete, that main drains had been laid, but the house-drains had not been connected; but this argument is fully answered in the report[1] of the Permanent Committee of the Sanitary Board, dated two days after the President's opinion was given, which states:—

"The Chinese are so ignorant and careless in all matters of drainage that the new methods of drainage, sound and good in themselves, are so abused that the effect is very little less injurious than that of the old methods. Traps and pipes are so constantly broken and choked that the sewage equally reaches the subsoil."

This was four years after the new drains had been begun. It will be interesting, therefore, to learn more of the attitude of the native population, and this is indicated by the following extract from the Governor's despatch on the plague to the Secretary of State, dated 20th June, 1894:—

"At this time, about the 21st May, the greatest dissatisfaction was shown by the Chinese community in regard to the method of sanitation we were employing. Complaints were made that the privacy of women's apartments was being invaded, and that women and children were being 'frightened out of their wits' by the daily visits of the military and police.

"On inquiry I found that these complaints were much exaggerated, and that the majority of the Chinese, after being made to understand what the object was which the Government had in view, did not object to the visitation, but even assisted those deputed to search their houses and to disinfect and cleanse them

[1] "Letter from the Permanent Committee of the Sanitary Board to the Government," dated 29th June, 1894, addressed to the Acting Colonial Secretary.

when necessary. A large deputation of Chinese waited on me, nevertheless, requesting that the house-to-house visitation should cease, and that they might take their sick away from the 'Hygeia' (Hospital ship) and the Kennedy town Hospital altogether."

This opposition of the native population was not so much to the introduction of European methods of sanitation, as to the house-to-house visitation consequent on the plague; nevertheless these facts form a valuable indication of the difficulties which beset sanitary reform.

The system of sewage-disposal adopted, although superior to that of using the storm-channels for the water-carriage of the sewage, does not appear to be in all respects satisfactory under the conditions obtaining in Hong Kong. Besides the difficulties attending the water-carriage of sewage in a town so situated, the successful connection of some of the house-drains in the native quarter, involving the possible introduction of water-closets, previously unknown, constitutes a serious obstacle. It is open to question whether the simple hand-carriage of excreta, notwithstanding the admitted defects of the method, would not have been preferable as the less of two evils. It is well known in the East that whereas native contractors require to be paid highly to remove by hand-carriage excreta from European houses, they will give a large sum per annum for the privilege of obtaining that from native houses, for agricultural purposes, for which they find the former much less valuable. Mr. Dibdin found the amount of nitrogen present in London solids as little as 0·041 per cent., and phosphoric acid 0·11 per cent.; more vegetable and less animal refuse, the product of a rice-eating people, would probably be richer in these ingredients, would putrefy more slowly, and would therefore be more valuable as manure.

Apart from the difficulty of tidal block, which might be minimised by high and small discharges, the Author favours the view that there are no engineering difficulties to prevent the ultimate success of water-carriage in Hong Kong, "assuming always that the house-drains are in order."

In considering the question of the possible introduction of water-closets in the native quarter, the Author urges that what is chiefly desirable is a more definite separation of the localities inhabited by natives, from those following the customs and habits of cleanliness usual amongst European races. The large central business portion of the town, already mentioned, seems to have been looked upon as subject to foreign principles, though inhabited

mainly by Chinese; and in the report previously referred to the hope is expressed that the usages of European houses will extend to the Chinese, and all can then be sewered alike on Western principles. The records of the plague, however, seem to indicate that such a hope is futile, and undesirable as race distinctions may appear, the Author advocates that a definite district or section of the town, extending right across from sea to hill, be laid out, in which European habits, the use of water-closets, large areas for light and air, and a rigorous sanitary house-to-house visitation, be insisted upon, on the lines of the strictest European municipal customs; and that only those content to observe and able to appreciate such advantages be permitted to live there. This must of necessity include a limited number of native servants, but not their families or homes. This district should be drained on the separate system with small pipes, and water-carriage for excreta should be provided from each building.

In the native town, outside this area (largely owned by Europeans, though inhabited mainly by Chinese), hand-carriage of excreta, as well as all other refuse, should be rigorously carried out by public scavengers daily at whatever cost; and water-carriage of sewage and water-closets should be forbidden by law. The model native tenement should have an open channel through a public scavenging lane formed behind the kitchens. If pipe drains from the latter be necessary for sinks, they should discharge into this channel in the open without traps;[1] this open channel should be cleansed daily by public scavengers at public expense, the solids being carried away and the liquids with the surface water being washed down carefully-laid pipe drains leading from trapped gullies, by the abundance of water which the absence of internal house supplies would render available. Public hydrants should supply the natives with water, and public latrines should be provided with efficient hand-carriage of solids, liberally maintained at the public expense.

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[1] In Her Majesty's prisons in Scotland there is not a laundry with a trap below a wash-tub, nor a kitchen with a trap below a sink; all discharge in the open.

(*Paper No. 3143.*)

"Electric-Transmission Plants at Moodie's, De Kaap Goldfields, Transvaal."

By Henry James Shedlock Heather, B.A., Assoc. M. Inst. C.E.

Moodie's Gold Mining and Exploration Company, Limited, was floated in 1884 for the purpose of acquiring thirteen farms, having a total area of 79,656 acres, situated along the edge of the Kaap Valley in the district of Lydenburg, South Africa. The farms are very well watered by a large number of springs, mostly small, but the majority proceeding from sources near the summits of the mountain ranges. This circumstance, upon the discovery that quartz reefs existed on the property, which had hitherto produced alluvial gold only, naturally resulted in attempts to utilize the power available, and most of the companies holding mining claims on Moodie's ground put down pipe lines and Pelton water-wheels for running their crushing and mining plant.

At first, while operations were being conducted on a small scale only, this method of obtaining power was found to be economical and satisfactory, but as development proceeded, and larger and heavier mills were used and required to be run regularly, the system was found to present some serious drawbacks. During the six winter months, April to September, there is practically no rainfall, and evaporation goes on very rapidly. Tropical thunderstorms, causing dangerous floods on the mountain streams, are of frequent occurrence throughout the remaining six months of the year. The mean annual rainfall varies at different points of the property between 30 inches and 50 inches. The irregularity in the amount of water available placed small water-power plants at a great disadvantage. It was not worth while for the mining companies leasing claims on Moodie's, each of which required only a small amount of power, to construct dams, which, to withstand the summer freshets, would require to be very substantially built, and the loss by evaporation sometimes proved to be enormous. In the case of one property in the neigh-

bourhood, it was found that in winter, from midnight to sunrise, the water-power available was sufficient to drive twenty stamps; during the day the water fell off to such an extent that by sunset only five stamps could be driven, and these not at full speed; by midnight again the full twenty stamps could be set to work. These considerations induced Moodie's Company in 1891 to investigate the question of establishing a central generating station, and of transmitting power thence to the mines electrically.

Hydraulic Works.—It was found that at a point on the Queen's River, the largest of the streams running through the property, a fall of 150 feet obtained, and measurements of the volume of water showed that, at the lowest ordinary winter level, a minimum of 500 HP. could be developed. The nature of the country made the cost of a dam of sufficient size to hold back the summer water for use during winter quite prohibitive; accordingly only a small dam was constructed. This dam, however, as well as the intake walls, had to be built in the most solid manner to withstand the violence of floods. A water-race, about 2,000 feet long, of which 265 feet was tunnelled through a ridge composed mainly of loose boulders, brought the water to the head of the pipe line. This was designed to take 2,300 cubic feet of water per minute, which it was expected would develop 500 HP. For the first 360 feet of its length the pipe diminished in diameter from 30 inches to 26 inches; it then entered a Y-piece to which valves were fitted. From this point, at first, one branch only of the Y was carried on, as the initial power requirements were not expected to necessitate the installation of more than half of the final plant. This branch was 20 inches in diameter and 110 feet in length; it was also divided into two branches, each 16 inches in diameter, and these carried the water to two nozzles connected to the pipes by ball and socket joints. Each of these nozzles operated one 6-foot Pelton wheel, to the shaft of which was keyed a grooved pulley, 6 feet in diameter, adapted to take five driving-ropes of 1½ inch in diameter. Each wheel was fitted with a "Doolittle" regulating gear, which raised or lowered the deflecting nozzles between two extreme positions in which the whole or none, respectively, of the water passing through the nozzles, impinged on the wheel buckets. To obtain constancy of speed, one side of a differential gear was driven by the power wheel and the other side by a small auxiliary Pelton wheel, which, having no other work to do than the overcoming of friction, and being under a constant head of water, would presumably run at a constant speed. When the main Pelton was running at its proper speed, no movement of the nozzle

took place; when, however, it slowed or quickened, in consequence of an increase or decrease in its load, the corresponding portion of the differential gear was also retarded or accelerated. The other half maintaining a constant speed, a movement of the intermediate gear at once took place, with the result that the nozzle was shifted, and more or less of the water was allowed to impinge on the wheel buckets, so that the speed was brought right again. The whole of these pipes, wheels, and regulating gear were supplied by the Pelton Water-Wheel Company of San Francisco and New York.

When tenders were invited for the supply of the electrical gear, no stipulations were made by Moodie's Company as to the system to be adopted; it was merely specified that the transmission should take place from the generating station on the Queen's River to the Company's office, which was 4½ miles distant, that from there it should proceed to six different specified mines, being distributed in certain proportions, that the pressure at the mine motors should not exceed 500 volts, that lightning arresters of one of two specified types should be fitted, and that telephonic communication between all points of the system should be arranged for. Contractors were to state the total amount of power they would undertake to deliver at the various mines, that produced by the two Pelton wheels being guaranteed by the Company to be 250 HP. The contract was let to Messrs. W. T. Goolden and Company, of London, on the 30th October, 1893, and it was on this date that the Author's connection with the plant commenced. The contractors had unfortunately stated the power they undertook to deliver at the mines in terms of what they called "electrical horse-power" going into the motors, instead of brake horse-power obtainable from them, which, of course, was what Moodie's Company wished to know. The actual available total was expected to be 112 brake horse-power, showing an efficiency on their contract of about 45 per cent. only, from Pelton pulley to motor belts.

Generating Plant.—The system adopted by Messrs. Goolden and Company was to install at the generating station two separately excited continuous-current generators, mechanically coupled together and connected in series. Each machine was wound to give 1,500 volts and 55 amperes at 500 revolutions per minute, so that current was to be delivered from the generating station at a pressure of 3,000 volts. It was to be conveyed along four No. 6 standard wire gauge high conductivity copper wires in parallel (*i.e.*, eight wires, including returns), placed on poles so that the lowest of the wires should be at a minimum height of 12 feet

from the ground, over the distance of 23,700 feet to Moodie's Company's office, where, it was calculated, the pressure at full load would be 2,817 volts; at this point the power was to actuate two motor-generators in a distributing station, the high-tension current passing through the motor armatures of these machines in series, while the generator armatures were connected in parallel and together were to give 131,000 watts at 625 volts. From the low-tension switchboard at this building the power was to be divided among five separate circuits and so distributed to the six points at which it was required, two of the mines being served by one circuit. The lowest pressure at the mines was to be 418 volts, and the highest 550 volts.

Conductors.—On the Author taking charge of the contract, early in November 1893, on behalf of Messrs. Goolden and Company, it was found that a slight modification of the gauges of the wire, the total weight remaining the same, would result in a slightly increased plant efficiency, without necessitating the use of so many different gauges as to be likely to cause confusion in the field. For the power wires, therefore, the undermentioned four sizes and test figures were decided upon, the material being hard-drawn copper:—

Weight per Mile.	Approximate Diameter.	Minimum Breaking Stress for Standard Weight.	Maximum Resistance per Mile at 60° F. for Standard Weight.	Minimum Number of Twists to be stood without Fracture.
Lbs.	Mils.	Lbs.	Ohms.	
761·6	218·5	2,280	1·1686	16 in 6 inches.
540·0	184·0	1,620	1·648	21 „ 6 „
400·0	158·0	1,250	2·225	25 „ 6 „
250·0	125·0	800	3·56	14 „ 3 „

For the telephone circuits, silicon-bronze wire, 64 mils in diameter, was procured, weighing 65 lbs. per mile, with a minimum breaking stress for standard weight of 292 lbs., and a resistance of 31 ohms per mile. The total weight of power-wire (copper) amounted to 70,000 lbs., and the length of the telephone wire was 45,000 yards. On the copper power-wire a variation between 3 per cent. above and 3 per cent. below the specified standard weights was allowed, and differences in other particulars to correspond. On testing the wire it was found to fully comply with the specification. It was decided to use insulators of brown earthenware on the lines, those for the power-wires being of the Johnson and Phillips pattern, with double flange and a separate cup, which

could be lowered down the insulator bolt to receive insulating oil, which, when the cup was raised into position, immersed the inner rim of the insulator proper. Instead of the usual means of attachment to the bolt, a coarse thread was cut in the hole in the earthenware fitting, and a corresponding thread on the bolt, as used on the English Post-Office telegraph lines. No shackle insulators were used. The poles and cross-arms were of iron, and were shipped for South Africa with the rest of the line material on 24th February, 1894, in order that, on arrival, this portion of the work could be proceeded with, the Author remaining in England to supervise the building of the machines.

Generators.—The generators were constructed with armatures of the Gramme type, chosen as being more quickly repaired than drums, and their hard-drawn copper commutators contained one hundred and sixty sections. The pole-pieces and magnet-bars, of the Manchester pattern, were all of wrought-iron and were bolted to two 12 inches by 6 inches H-iron girders running along the machine. To these also were fixed the three pedestals carrying the bearings. Each shaft was furnished at its end with a flange fitted with two gun-metal studs. A plate with four slots engaged the two studs of both generator shafts, and being otherwise unsupported, constituted a flexible connection between the two machines. The rope pulleys were turned with five grooves in each, with the idea of using five separate ropes for each machine. The magnets were wound to be separately excited from a 100-volt circuit, and were estimated to require 18 amperes for each machine. Two exciters, each capable of giving as normal load 30 amperes at 100 volts, were supplied, so that at a pinch one exciter could serve both machines. Pulleys on the generator shafts were arranged to drive these exciters.

The motor armatures of the motor generators (or transformers) were exactly similar to, and interchangeable with, the generator armatures; it was thought that by adopting this arrangement one spare armature would be sufficient as a stand-by for both generating and distributing stations. On arrival at the spot it was evident that this provision would have been of very little practical use, as even at the best time of the year it would have been impossible to get one of these armatures weighing 50 cwt. from the one point to the other and fitted into place in less time than 5 days, and 3 weeks might have been required in bad weather. The motor field-magnets and pole-pieces of the motor generators were somewhat smaller in section than those of the high-tension generators; these, and the bearing pedestals, were

bolted to H-iron girders, as in the case of the generators, these girders also forming the foundation-frames of the low-tension generators. Each of the high-tension motor armatures was bolted by a rigid flanged coupling to the armature of a low-tension (625 volts) generator, the field-magnets of which were also of the Manchester type and entirely of wrought iron. The two transformer sets so constituted were coupled by a flexible coupling exactly similar to that made for the high-tension generators. Electrically, the two motor armatures were, under ordinary conditions, to be connected in series across the high-tension lines, and the two low-tension generator armatures in parallel across the low-tension lines. The fields of both high- and low-tension machines at the distributing station were arranged as shunts across the low-tension leads, with the addition in the case of the motors of a few turns (giving at full current about 10 per cent. of the total excitation) connected in series with the motor armatures and taking, of course, the high-tension current. These series turns were put in to make the transforming combination self-starting.

One of the first points which called for attention was the large size of the generator driving-ropes in comparison with the diameter of the pulley that would be required to give the normal number of revolutions for a dynamo of the size to be used. The diameter of the driving pulleys on the Pelton shafts being 6 feet, and their speed at full load 150 revolutions per minute, it was necessary that the diameter of the driven pulleys on the dynamos should be only 22 inches in order to get 500 revolutions per minute. This was obviously too small for pulleys to be used with ropes 1½ inch in diameter. Attempts to procure an alteration in the size of the ropes were, however, not successful, owing to the driving pulleys having already been delivered in South Africa.

Switchboards.—The high-tension switchboards at the generating and distributing stations were almost exactly similar, the only differences arising from the different modes of excitation used in the two cases. Each high-tension machine, whether generator or motor, was provided with two single-pole switches which were closed or opened by string pulls, and also with two single-pole fuses. The lines were also fitted with a pair of switches and a pair of fuses, besides movable plug-connections which were made to engage with a locking-bar, so that the line plugs could not be moved while the switches were closed. To ensure greater safety to the attendants, it had been decided that one terminal of each generator and motor on the high-tension side should be earthed, so that the pressure between any part of the machines

or circuits and earth could in no case exceed 1,500 volts. The two earths (at the generating and distributing stations) were metallically connected by a wire of 250 lbs. weight per mile, carried on the lightning rods of the line poles, above the power-wires. In this earth wire were placed two ammeters, one on each high-tension switchboard. Besides this instrument, each high-tension board carried an ammeter and a voltmeter for each machine. The exciting board at the generating station was provided with a voltmeter and an ammeter for each exciter, a regulating-switch by which a varying resistance could be placed in the field-magnet circuit of each generator, and plugs by means of which the generator field-magnets could be connected in parallel in the circuit of either exciter. At the distributing station, the high-tension exciting boards carried regulating-switches and breaking-switches only. The low-tension switchboard at the distributing station carried a main double-pole switch, fuses, a voltmeter and an ammeter for each generator, and the same appliances, except a voltmeter, for each of the circuits. Each generator had also a shunt-regulating switch.

Motors.—In order to limit the number of necessary spare parts as much as possible, it was decided to supply ten exactly similar motors for converting the electrical into mechanical energy at the mines, and to connect one or more of them, as required, to the machinery to be driven. Each of these motors was designed to absorb 11 kilowatts at full load when its output was just over 11 HP. The motors were of the over-type with Gramme-wound armatures. The field magnets were shunt-wound, and an addition of 10 per cent. of the exciting ampere-turns was applied as a series winding to enable the motors to start easily. As the conditions under which these motors would have to work were uncertain, the armatures were enclosed in Goolden air-tight casings. Each motor was provided with an enclosed starting-switch, and as the resistance coils accompanying these were made sufficiently large to carry the full-load current the arrangement was capable of being used for speed-regulation as well as for starting. At first sight this appears to be an uneconomical method of effecting the desired regulation, but in the case of a water-driven plant not provided with any reservoir the want of economy is only apparent and not real. The same amount of energy must be wasted, whether it is dissipated in the form of heat produced in resistance coils placed in series with an armature across the mains, or lost in allowing water to fall without doing useful mechanical work, either through a by-pass or overflow,

or, as in the case of a Pelton wheel, by directing it clear of the wheel-buckets.

Protection against Lightning.—When the building of the plant was approaching completion, information reached England that excessive difficulty was being experienced by the Sheba Gold-Mining Company, whose mine is in the same district as Moodie's Company's property, in running their electrical plant, by reason of the severity of the thunderstorms in that part of the country. It was at first suggested that on Moodie's Company's plant underground cables might be laid instead of the overhead wires contracted for, but when it was shown that the cost of the cables and of laying them in such a country would be enormous, it was decided that the best protection was to shut down the plant during the occurrence of storms, the machines, of course, being disconnected from the lines. At the same time, the adoption of extra precautions against the effects of lightning was authorized. Amongst other proposals made was that of insulating the frames of the machines from earth, but it was considered at the time that the value of this as a means of protection would be discounted by the extra risk to the attendants involved in running the machines. Subsequent experience has shown that the insulation of the frames of generators and transformers connected to overhead lines is almost universally regarded as essential in South Africa.

The lightning arrester which had previously been selected for use on the lines was that known as the "Keystone," which had apparently been as successful as any other. In this arrester two carbon pencils, hung on pivots, project through openings, which they nearly fill, in the sides of an otherwise air-tight chamber. The two pencils are connected, one to earth, and the other to the line, and their two extremities are brought to within about $\frac{1}{16}$ inch of one another. On the passing of a discharge, occasioned by lightning, from one to the other, the dynamo current may or may not follow. Should it do so, the resulting arc instantly heats the air in the chamber; the consequent expansion of the air at once causes the pivoted carbon pencils to fly back on their hinges, lengthening the arc until it is broken. The separated pencils are brought back to their original positions by the action of gravity, and are ready for the next discharge. The nature of such further protective devices as were to be adopted formed the subject of discussion between the consulting engineer for Moodie's Company, Sir William Preece, K.C.B., and the contractors, after the Author had left England with the machinery. The decisions arrived at are subsequently referred to.

The lightning arresters adopted for the telephone circuits were of the standard Post-Office pattern, consisting of three metal plates insulated from one another, but clamped together, with sheets of mica, each perforated with three holes, placed between the plates. The centre plate is connected to earth, and the two outside plates to the lines; any discharge passing from line to earth arcs through the air-space formed by the perforations in the mica.

Testing.—From the foregoing description of the plant it will be seen that every machine was in duplicate. There were two exciters, two generators, two motor-generators, and ten small motors. The separate portions of the plant could therefore be run at full load and could be satisfactorily tested by means of Dr. Hopkinson's method, or by the modification of it in which the losses in a pair of machines are made up electrically instead of mechanically. The presence of the flexible couplings already referred to on the shafts of both generators and motor-generators still further increased the applicability of the method in the present instance. It is to be regretted that, with conditions so favourable, time was wanting to take a more exhaustive series of measurements. A sufficient number of readings was, however, taken to enable the efficiencies of the larger machines to be arrived at, with a considerable degree of accuracy. The test runs occupied 6 hours each, and results of the readings taken gave, as a mean value for the efficiency of the 1,500-volt generators and motors, 89·7 per cent., while that for the 625-volt generators was 91·2 per cent.

The larger machines thus showed a lower efficiency than the smaller ones—a result which, as the machines were of identical types, was somewhat unexpected. The larger high-tension machines, however, were found to be capable of taking a considerably higher load than they were set to do in this instance. That this was so was further indicated by the temperature rises of the armatures, which amounted to about 70° F. on the smaller low-tension machines, and 60° F. on the larger. At the conclusion of the 6-hour test runs all four of the high-tension machines were run on open circuit at a pressure of 2,000 volts, with one terminal earthed in order to make certain that it would be safe to use the earthed central or neutral wire which it was proposed to employ when the plant was erected.

The self-starting capability of the high-tension motors was next tried. It was found that 66 amperes, passing through the series coils and armature of one of the motors, sufficed to start the whole combination, namely, the idle motor and the two low-tension generators, and that with this current, in spite of the weakness

of the field, there was no appreciable sparking at the commutator. The start once effected, 20 amperes to 30 amperes brought the machines up to full speed. The ten 11-kilowatt motors were tested in pairs by the same modification of the Hopkinson method, but, not being provided with couplings like the larger machines, each motor had to be set to drive its dynamo by belt. Their efficiency proved to be about 80 per cent. As soon as the testing was completed, all the machines were despatched to their destination under the Author's charge.

General.—On arrival at the spot, it was found that Moodie's Company's power requirements had undergone considerable changes during the time that had elapsed since the signing of the contract. Some of the mines which had previously applied for the power had ceased working, and did not now require it, whilst new properties had been started, and wished to have machinery driven by electricity. As the general tendency of the alterations had been to remove the centre of the district where power was to be delivered further from the generating station, the first step was to endeavour to find a more favourably situated site for the distributing station. A disused house, 1¼ mile further on, was fixed upon, and at the same time the continuation of the high-tension line, of which about 3 miles had already been constructed, of eight wires of 540 lbs. each per mile (*i.e.*, four in parallel), was carried on with the 761-lb. wire instead of the 540-lb. wire, in order, as far as practicable without undoing finished work, to preserve the best proportion between the losses on the high-tension and low-tension portions of the system. The arrangement of the ten motors finally decided upon was the following:—

	Motors.
At the United Ivy Company's mill	2
" " " " winze	1
" Ivy Extension Company's mill	2
" " " " shaft	1
" Agnes Company's mill	1
" Fortuna " "	3

Of these mills, that of the Ivy Company was in process of erection; the building of the Ivy Extension mill was not commenced, but it was intended to erect it immediately adjacent to the Ivy Company's mill. The motors at the shaft and at the winze were to be used for hoisting. The Agnes mill was being erected, but the Fortuna Company had not then commenced work on the battery. To supply all these, two trunk lines were necessary, one to serve the Fortuna Company only, at a distance, as ascertained

from preliminary chaining, of about 5 miles, and the other leading first to the Ivy mill, at a distance of 7,000 feet, and thence branching on the one hand to the Agnes mill, 2,300 feet further, and on the other hand to the Ivy winze, a distance of 1,050 feet, and thence 600 feet further, to the Ivy Extension shaft. The various amounts of power and the places at which the motors were required being thus re-settled, an entirely new scheme of wiring had to be got out as quickly as possible, and the work was made somewhat troublesome by the fact that only three sizes of wire were available. The fourth of the sizes brought from England, viz., that weighing 250 lbs. per mile, was only intended for use as the middle- or earth-wire on the high-tension portion of the system, and was by this time all utilized. As it happened, the three sizes at hand fitted in very well, and the Fortuna line was the only one of the low-tension system on which it was found impossible to run the same numbers and sizes of wires over the whole line.

The wires were run thus:—for the Ivy Company's mill and the adjacent Ivy Extension Company's mill together, two wires of 761·6 lbs. per mile outgoing, and two return; for the Agnes mill, one 540-lb. wire outgoing, and one return; for the Ivy Company's winze, one 540-lb. wire outgoing, and one return; for the Ivy Extension Company's hoist, one 540-lb. wire outgoing, and one return.

From the distributing station, therefore, to the Ivy Company's mill, there were in all (inclusive of return wires) ten power-wires. Four of these were continued to the Ivy mill, two branched off to the Agnes mill, and four entered the Ivy Extension winze. Two of these were taken in at that point, and the remaining two were carried on to the Ivy hoist. The remainder of the power-wire was put on the line to the Fortuna mill, starting from the distributing station with three 761·6-lb. wires, two 540-lb. wires, and one 400-lb. wire, all in parallel outgoing, and the same as returns. About 3½ miles along the way, the 540-lb. wire came to an end, and the line was completed with the three 761·6-lb. wires, and one 400-lb. wire on each side. One telephone wire was carried from the distributing station to the Fortuna mill, and two to the Ivy mill. As these lines were to be used with an earth return, the latter were sufficient for two stations, and it being evident that at first only those stations at the Ivy and Agnes mills would be required on this line, it was decided to erect no more telephone wires until later developments should prove that they were necessary. The subsequent amalgamation of the Ivy and Ivy Extension

Companies caused some modification of the original intention as to the use of the wires as erected. The Ivy Company abandoned its winze, making use of the Extension Company's shaft instead, and consequently the wires to the former were taken down as far back as to the Ivy mill, from which point they were then carried on, in addition to the two existing wires, to the Agnes Company's mill, which it was expected would be enlarged later.

The construction of the line does not call for much comment, except that the country was found to be particularly difficult, owing to its roughness. This was especially the case with the line from the distributing station to the Ivy mill, which ascended a range of hills in a sidelong direction, the difference in levels of the two points, about 7,000 feet apart, being over 1,200 feet. One mile of the high-tension line showed a still steeper slope, and there were several short pieces on both lines at a slope exceeding 1 in 2. The high-tension line was the first completed, a week or two before the generators at one end and the motor-generators at the other were ready to run. Tests of the line before starting showed dead earths on several of the eight separate wires, which were found to be due to the heads of many of the insulators having been broken off by the inductive effects of lightning, the wires having in many cases dropped upon the iron cross-arms. The search for the broken insulators revealed the fact that no reliance could be placed in the use of oil in the power insulators. In many instances the oil had dried, in the course of a few months under the hot sun, and in other cases, particularly on the upper tier of wires, the heavy rains had apparently splashed from the upper surface of the cross-arms and displaced the oil. The use of oil was accordingly abandoned. In order to make it possible that the breaking of one or two insulators should not entirely shut down the plant, every wire was provided with a separate fuse at each end; this arrangement on many subsequent occasions enabled a shut-down to be postponed until a favourable opportunity arrived.

Instructions had been received from the contractors in England that the extra precautions to be taken against damage by lightning were to include the fitting of barbs to the earth-wire over the high-tension line, and the use over all the low-tension lines of an ordinary galvanized-iron barbed fencing-wire secured along the tops of the poles. Additional lightning arresters for the high-tension line, consisting of banks of Wurts' charred-wood arresters separated by choking-coils, were also sent out. The earth wire on the high-tension line was accord-

ingly taken down, fitted with barbs and re-strained, whilst fencing-wire was put up throughout the low-tension part of the system. Meanwhile the line to the Ivy mill had been completed, and it, as well as the generating station, had been connected by telephone to the distributing station, the two stations being served by a completely insulated circuit, whilst the line to the Ivy mill had an earth-return which was now supplemented by the barbed fencing-wire erected as a protection against lightning. The high-tension part of the plant was then started, with its earth or middle wire connected at both ends. As a result of this, the telephone bells at both ends of the Ivy line at once commenced to ring continuously. On disconnecting the earth-wire from the machines at each end of the high-tension line this trouble was at once removed, and the plant was always subsequently run in this way. Although the outgoing and return telephone wires on the high-tension line amounted to a length of 11½ miles, were not crossed over anywhere, and ran parallel with the outgoing and return power-wires, and at a distance from them of only 2 feet, no trouble whatever was experienced from induction. This was equally true of the telephone circuits using an earth-return on the low-tension lines, such difficulty as was experienced in hearing on these instruments arising entirely from the noise of the mills and other machinery.

Stamp-Mills.—The Ivy Company's mill was the first part of the machinery ready to be run. It was a ten-stamp mill by Sandycroft, each stamp weighing 950 lbs.; the drop required was 8 inches, and the speed ninety-two blows per minute. In addition to the ten stamps, four Scoular concentrating tables were arranged to be driven off the mill line-shaft, and a 15-inch Blake-Marsden stone-breaker was also fitted, being provided with fast and loose pulleys, as it was not required to run continuously. The Author found on inquiry that local ideas as to what power such a mill was likely to require were vague in the extreme. It was generally considered that stamp mills required 1½ HP. per stamp, and the weight, speed, and height of drop were evidently not considered to affect the question to any great extent. This vagueness no doubt arose largely from the general use of water-power in the district, but it was to some extent caused by the persistency of many steam-engine builders in adhering in their price lists to the term "nominal" horse-power, a qualification as much to be deprecated as that of "electrical" horse-power. In the present instance it was clear that the actual work being done in the stamps would approach closely to 18 HP., and as the

Scoular tables would obviously absorb something, though not very much, and friction throughout had to be allowed for, it was doubtful whether the two motors, having together an output of 22 HP., would be strong enough to drive the mill without the stone-breaker. The attempt was, however, made, and two of the motors were accordingly connected by a friction-cone coupling, which served also as a pulley to drive the mill line-shaft by a single belt. When the extra friction, which is always present when new machinery is first started, had been got rid of, it was found that the 22 HP. was just sufficient, under normal circumstances, to drive the ten stamps and the four Scoular tables, the drop at first being set at 6½ inches to 7 inches. As, however, variations in the amount of power required, amounting to as much as 10 per cent., occurred frequently during running, it at once became necessary, in order to avoid overloading the motors, to hang up one of the ten stamps. To remedy this state of things, Moodie's Company ordered from Johannesburg a 45-HP. motor, intending to use it to drive both the Ivy Company's mill and that of the Extension Company, the latter company having by this time been absorbed by the former. The Extension mill was erected in line with the other, and having only ten 750-lb. stamps, while it was geared to run at only eighty blows per minute, it was clear that it, with the Ivy mill, would not form a load above the driving capacity of the 45-HP. motor.

A similar experience was met with at the Agnes mill, which was started within a few days of the other. The ten stamps here weighed between 700 lbs. and 750 lbs. each (the mill being an old one); the drop was fixed at about 5 inches, and the mill was geared to run at seventy-five blows per minute. Having no other size of motor, the Author fitted one of the 11-HP. motors. This also proved capable of just running the mill at ordinary times, but was not powerful enough to keep more than nine of the ten stamps going when the load was unusually heavy. In this case also a larger motor was ordered by Moodie's Company. Both this motor and that procured to run the Ivy battery were supplied by Messrs. J. H. Davies and Company of Johannesburg, and were shunt-wound motors with drum armatures, made by the Electric Construction Corporation. Some months after the starting of the two mills referred to, the Fortuna battery was connected to the system. This was also a ten-stamp mill, built by Messrs. Fraser and Chalmers. The stamps were of the same weight as those at the Ivy mill, and were intended to be set at the same drop, and run at the same speed. This mill appeared to take somewhat

more power than was required at the Ivy mill, but this was probably due to two extraneous circumstances, namely, that two motors (by the Electric Construction Corporation) instead of one, were used, and that these two drove by separate belts an intermediate counter-shaft, from which there was another belt-drive to the mill line-shaft. As this mill, however, only ran for about two months, it can hardly be considered to have got into proper running order at all.

Speed Regulation.—About a year from the start, a 12-HP. hoist was put down by the Ivy Company. This was run by a series-wound motor, also built by the Electric Construction Corporation. By this time the Author had found that the sudden variations in load which a hoist motor would have to deal with, bearing in mind that it would be impossible for the attendant to give notice by telephone every time he wished to start or stop a cage, would cause considerable speed variations over the whole system. To meet this, therefore, the Author insisted that a dead-load resistance, as nearly as possible equivalent to the live load, should be so arranged that it could be used as a starting resistance, and would also be switched into circuit whenever the motor was off. This substituted load was applied by the same switch that was used for speed regulation of the motor, so that, so far as the attendant was concerned, no additional complication whatever was introduced. The arrangement worked quite satisfactorily, its supposed want of economy not being realised in practice.

Although regulating switches were provided in the field-magnet circuits of both the motor and the generator at the distributing station, they proved to be practically useless in adjusting motor speeds; when an attempt was made at the distributing station to lower the pressure by means of these switches, the speeds of the mill and other motors were reduced, and unless this reduction was immediately noticed and counteracted by the motor switches at the mills (and this as a rule was not done in time), a less amount of power, corresponding to the lower speeds, was then being supplied from the distributing station. At the same time, if no shutting-off of power at the generating station took place simultaneously, the distributing station was still receiving the same amount of power, although it was delivering less than before. Accordingly, the speed of the machines there became accelerated until the outgoing pressure, which for about a minute had been lowered by the regulating switches, was raised again by the increased speed to its former amount; the old state of things recurred, and no permanent lowering of the voltage was secured.

The distributing station had, therefore, no control over the system, and the only means by which this could be remedied was by introducing some means of absorbing fairly large quantities of power. These means were subsequently provided in the shape of resistance coils across the low-tension mains, but the primary purpose of these was rather to keep things going when the telephone service had broken down than to regulate the speed. The Author had early concluded that such regulation could best be effected entirely at the source of power, *i.e.*, at the generating station. In order to keep the voltage given by the low-tension generators constant, the machines, being shunt-wound, had to be driven at a higher speed when under a heavier load. Consequently the motors to which they were coupled had also to run at a higher speed under a heavier load; they, therefore, being practically shunt-wound machines, had to be supplied at a higher pressure at such times, and therefore the high-tension generators at the generating station had also to give an increased voltage when under heavy load, and the extent of the necessary increase in voltage was magnified by the increased drop on the line. Given constant speed, these conditions might have been to some extent met by over-compounding the high-tension generators, but, unfortunately, they were separately excited.

Supposing, however, that, as the electrical arrangements were, these generators had been run at constant speed, then the low-tension voltage would have had to be kept constant by regulating the high-tension voltage at the generating station by hand for every particular ampere load, by means of the magnet regulators on the exciter switch-boards, every change of load requiring a corresponding change in the position of the regulating-switches. Since the automatic governors on the Pelton wheels might not (and actually when tried did not) secure constant speed on the generators, the Author concluded that the simplest plan was to abandon the use of the Pelton wheel speed-governors, and to control the Pelton nozzles directly by hand, through gearing from the switchboard; that is to say, the Author preferred to regulate the low-tension voltage by regulating the power supply by hand, rather than to rely upon the latter being done automatically while the voltage still had to be regulated by hand.

Working.—On the whole, the plant described worked satisfactorily, as far as the running time was concerned. The months September to March have in each year a much higher stoppage account charged against them than have the months April to

August. This is due to the fact that it was considered advisable in view of the difficulty of protecting a continuous-current plant against lightning, to shut down the machinery when a thunderstorm was in progress over the lines, most of these storms occurring during the months September to March. For these months the average stoppage was 37 hours 40 minutes per month of 26 short days. For the other months in the year, the average stoppage was 12 hours 9 minutes, so that with the old plant thunderstorms may be considered to have caused about 25½ hours stoppage per month during 7 months of the year. This, however, cannot really be taken as representing the time lost through storms, not only on account of the months at that time representing less than 26 days each, but also because on three separate occasions, although instructions had been issued that the plant was to be shut down on the approach of storms, lightning damaged one of the large machines before the presence of a storm was suspected. On each occasion this involved the shutting down of half the plant during repairs, which occupied, on an average, about 10 days. Viewed in the light of later developments in the electric transmission of power, the strong points of this system were the great starting power of the motors, and the possibility of regulating the speed of each motor at its own switchboard. In most cases this was effected by the insertion of a resistance in series with the armature, an arrangement which, as already explained, is wasteful where coal is the source of power, but which was not really so in the present case, as there was no possibility of storing any water that was not being utilized. The weak points, however, more than counterbalanced the advantages. They were:—

1. The very low efficiency of the system. The efficiency of the original scheme, as estimated by calculation, reckoning from generator switchboard to motor pulley, was only 51·5 per cent., and in actual practice (the original scheme having been modified to suit new requirements) it would only have been, at full load, 47 per cent.

2. The cost of upkeep of the distributing-station, which, with a staff of three Europeans and about six natives, amounted very nearly to £100 per month.

3. The impossibility of running this (and apparently any other) continuous-current plant through such thunderstorms as occur in the district. Although no attempt was ever made to do this, the fact that machines were broken down on three occasions by lightning, although they were cut off from the lines whenever a

storm was seen to be approaching, seems to prove conclusively that the attempt would have been futile.

4. The uncertainty of the telephone system, which was a necessary adjunct. This uncertainty arose in the main from the liability of the thin telephone-wires to come in contact with the power-wires by birds striking them, and during gales, and would have been to a great extent done away with if the telephone wires had had a separate line of poles to themselves.

New Plant.

Consideration of the first three of these disadvantages, by the end of 1895, induced the directors of Moodie's Gold Mining and Exploration Company, Limited—into whose service the Author passed about that time, taking charge of both electrical and water-power plant—to invite tenders for the substitution of more modern machinery for that then in use, with the result that Messrs. Rennert and Lenz, of Johannesburg, obtained a contract to supply a three-phase alternating-current plant of 500 HP.—double the capacity of the old one. They proposed to adopt a pressure of 10,000 volts for the transmission, undertook that the distributing station should be done away with, guaranteed that their plant, with a portion only of the wire on the existing lines, should give an efficiency of 80 per cent. from generator switchboard to motor pulleys, that it should run through thunderstorms, and would not require any telephone system. They decided upon using the existing insulators, but insisted on having wooden arms substituted for the iron ones then in use. To this change the Author strongly objected, pointing out the mechanical disadvantages of using wood for cross arms, namely, its weakness, liability to shrinkage, which would cause the arms to become loose on the poles, and the fact that the life of wood in a tropical country is exceedingly short, in spite of protective coatings of varnish or paint. The Author further made some measurements, which showed, in conjunction with line-insulation tests previously made, that the line insulation during rain would only be improved by about 1 per cent., even for a pressure of 100 volts, by the substitution of wood for iron. The new contractors, on the other hand, maintained that, in their experience, insulators on wooden arms were less liable to damage from lightning than were those on iron, and as the contractors had accepted the onus of making good any damage occurring within 15 months of the delivery of the new plant, the Author had to agree to their wishes in the matter. The

wooden arms, covered with five coats of copal varnish, were quickly supplied, and the work of substituting them for the iron arms was proceeded with on Sundays, whilst the old plant was shut down.

Conductors.—At the same time two of the wires on what was then the high-tension transmission line, namely, from the generating station to the distributing station, were removed, leaving on this portion six wires. These were used in the meantime as three outgoing and three return wires, and were intended to be applied later in three pairs, one pair for each of the three phases by which the transmission was subsequently to be effected. Up to the present date, however, of these six available wires three only have been put into use, the other three being left disconnected at both ends. At the same time all the wires on the Fortuna line (that mine at the time being shut down), excepting three, were taken down, these three being put on the wooden arms. In the case of the Ivy line, which then had ten wires as far as the Ivy mill, two were taken down and four were put on wooden arms (three of these wires being intended for use on the three-phase system), whilst the remaining four were not touched, the low-tension current continuing to be carried by them to the Ivy mill. These four, with one of those on the wooden arms, were to be taken down after the change of system had been effected. It was rendered possible by these means, and the weekly stoppage on Sundays, to get the whole of the working lines so arranged that they were capable of transmitting power by either system, with the exception of the portion immediately adjacent to the distributing station, which was to be cut out altogether. To accomplish this rapidly, a second line was run between points on the high-tension and low-tension lines, close to the station. Three wires were put up on this line, but were not connected at either end, this being deferred until the change was finally made.

Lightning-Arresters.—All the line work was satisfactorily carried out by the time the new machinery began to arrive. Lightning-arresters had then to be put up along the line as arranged by the new contractors. Ten sets of Wurts' non-arcking metal arresters, and ninety of a type made by the Allgemeine Elektricitäts Gesellschaft of Berlin were supplied. The former consist of a number of small metal cylinders placed side by side in a row, with small air-spaces between. The metal of which the cylinders are composed is an alloy selected on account of its small power of maintaining an electric arc. The other arresters consisted of alternate disks of tinned-iron and mica, threaded upon a vulcanite

spindle. The mica sparking-gaps numbered about sixty, and the total space of insulating material between line and earth was about 1½ inch. On the Wurts arresters (made by the Westinghouse Company) the total air-space between line and earth was slightly greater. Upon consultation with Messrs. Rennert and Lenz, it was decided to put up at first the German arresters only, leaving those of the Westinghouse Company for subsequent use as experience might suggest. Sets of the former were accordingly placed at every terminal point of the lines and also at intervals along them, the distance between two adjacent arresters on the same wire averaging about 1,000 yards, the points at which arresters were placed being largely those selected on account of experience having shown that damage from lightning was specially liable to occur at them.

Generators.—Four three-phase generators were provided, each capable of giving 100 kilowatts on a non-inductive load at a speed of 430 revolutions per minute and a pressure of 200 volts. They were of the inductor pattern with fourteen poles, giving at normal speed 50 cycles per second; the rotor of each generator consisted of a star-shaped steel casting furnished with laminated iron pole-pieces; the stator had two independent windings, one set being opposite to each set of pole-faces of the rotor; each of the two sets of windings gave 200 volts, and they were connected on the machines in parallel; the magnet-coils were wound on a former placed on the stationary portion of the machine, between the two sets of stator windings, so that there were no wires on the rotating portion, and consequently no brushes or collecting rings either on the magnet-circuit or on the armature-circuit. The coils producing the three differing phases were connected in "star" fashion. Each generator had its own exciter driven by a belt from a pulley on the generator shaft; the exciters were shunt wound, each capable of giving 50 amperes at 110 volts, the actual magnetizing current required for each generator at its full load being about 15 amperes, so that each exciter was capable of easily supplying the magnetizing current for two generators. The latter were designed to be arranged in pairs, each pair having its two exciters placed in parallel. On these generators ropes were used for driving, as before, but a better relation was observed between the diameter of the rope and that of the driven pulley. The latter was about 31½ inches, the rope 1 inch, and the driving pulley 7 feet 6 inches in diameter. On the driving pulley on the Pelton shaft there were twelve grooves, and on the driven pulley thirteen, a continuous rope with a tightening-pulley being used. The tight-

ening-pulley gear, as supplied, was better suited to a station having more available space than could be found in the one under consideration; the Author therefore had to modify it considerably, until in the end it was practically the same as that which had been added to the old plant, except that it ran on wheels instead of guide-rods. As the rails on which these wheels ran were placed at an inclination of about 1 in 4, it was found that the weight of the carriage was in itself sufficient to keep the rope strained to the proper tension. As a result of the improved relation between the diameter of the rope and that of the pulley, after 14 months' running the rope was still apparently sound, whereas those on the old plant, of the same class of manilla, were finished after 6 months at the best. The four generators were put in parallel (with the help of the ordinary lamp synchronising arrangement) on to "bus" bars on the switchboard, whence the current was conducted to a set of four transformers having a 50-to-1 ratio, so that the pressure was raised to 10,000 volts on the line.

Transformers.—Each of the four transformers at the generating station was of 100 kilowatts capacity on non-inductive load, and was designed for use with oil insulation, with a pumping gear and cooling apparatus for keeping the temperature of the oil down. The transformers at the motor-ends were all of 45 kilowatts capacity and were also arranged for oil insulation, but were not provided with circulating or cooling apparatus. The windings of all these transformers were connected on both high- and low-tension sides in the star form. The neutral points were not brought outside the transformers, and were insulated from the frames and from earth. The transformers were all of similar design. They consisted, so far as the iron is concerned, of two rings placed horizontally at the top and bottom, and connected by three equally-spaced vertical cores. The vertical cores were enclosed in cylindrical paper sheaths, on the outer side of which were the low-tension coils; these again were covered by other paper sheaths and cotton rope wound longitudinally, to serve as a spacing. Outside this were the high-tension coils, which were coaxial with the low-tension coils and cores.

Motors.—At first, three motors of 50 HP. each, and two of 30 HP. each, running, when fully loaded, at 570 revolutions per minute, were supplied. All of these motors were wound for 190 volts, and required fifty cycles per second to run at the speed indicated. The three 50-HP. motors, intended for the running of mills or other ordinarily uninterrupted load, had drum-wound stators fed from the low-tension leads coming from the

transformers; their rotors were short-circuited. Their efficiency at full load was 89·5 per cent., and the cosine of their angle of lag was 0·88. For the purpose of starting, they were provided with a liquid-resistance switch, made of iron blades which could be lowered gradually into a solution of carbonate of soda. This switch was put into the stator circuit, which was arranged for star connection. When the starting switch was "off," the separate rays of the star were not connected together. As the switch was being put in, a neutral point was established, the rays of the star being then connected through resistances which continually decreased as the switch was put "on," until in the final position metal contacts short-circuited the liquid resistance, and the inner ends of the star winding were thus connected, with no resistance between them except that in the switch leads. The stators of the two 30-HP. motors, instead of being drum-wound like those of the larger motors, were ring-wound. These motors gave an efficiency of 84·5 per cent. at full load, and the cosine of their angle of lag was 0·7. Both efficiency and cosine were somewhat low for a machine of this size, and, in fact, smaller machines by the same makers, as well as larger ones, give better efficiencies and cosines. The reason for this appears to be the fact that this particular size of machine was originally designed for a smaller output. The starting arrangements on these two motors were not the same. The one intended for the Agnes mill had a permanently short-circuited rotor, and a liquid resistance switch in the stator circuits exactly like the three 50-HP. motors. In the other 30-HP. motor, which was to work the Ivy hoist, necessarily an intermittent load, the rays of the star winding of the stator were permanently connected to a neutral point. The rotor circuits were, however, open, terminating in three collector-rings instead of a neutral point. Leads from brushes on these collector-rings were carried to a liquid-resistance switch exactly similar to those provided for the other motors, which gradually cut out resistance in the same way, except that in this case the resistance was applied to the rotor circuit, whereas in the others it was in the stator circuit. For reversing the direction of rotation of this motor, a switch was put into the stator circuit which reversed the direction of revolution of the field produced by the stator windings.

Working.—About 24 hours after the stoppage of the old plant, three-phase current was being transmitted over the wires. It was kept at a low voltage, the hoist motor being kept at its full-load current by short-circuiting and mechanically locking its

rotor. A thunderstorm took place within half an hour of starting the three-phase transmission. The plant got through this successfully and so gave rise to hopes which afterwards proved unjustified. After 24 hours' baking, a test of the motor gave a very satisfactory result, and it was accordingly set to work, the line voltage being then for the first time raised to the full 10,000 volts. Everything appeared to work satisfactorily, the line and the transformers all standing the pressure safely. The distributing station was now in use as a telephone exchange only, communications being conveyed from the hoist-room to the generating station, and *vice versâ*, with the help of an employee at the distributing station, who merely had to stand by to receive and repeat messages both ways. The telephone wires and the power wires were strained on the same poles, and were only about 2 feet apart; on the line from the hoist to the distributing station an earth return was used, whilst from the latter to the generating station a complete metallic circuit was employed. Neither telephone nor power wires were twisted, but were carried parallel to one another throughout. Nevertheless it was just possible to transmit speech by telephone whilst the new plant was running, although sometimes when a message, the substance of which was quite unexpected, had to be sent, it was found advisable, in order to ensure being understood, to give a bell signal for the plant to be shut down while the conversation took place.

All went well until midday of the 1st September, 1897, when, upon consultation by telephone with Mr. Wilms, the contractor's engineer, who was still at the generating station, the Author concluded that he could safely leave the hoist and go down to the generating station to see how things were going on there. He therefore started on the 3 hours' ride, only to find on arrival that the hoist transformer had broken down an hour earlier. Returning to the transformer room, it was found that the cotton insulation of the coils was still smouldering, and that it was extremely difficult, owing to the suffocating nature of the smoke, to get at the transformer. It was decided that the only way to save the rest of the coils was to fill the transformer case, which, so far, had not had the insulating oil put into it, with water. This was therefore done, and the transformer was left to cool. It was afterwards found that the coils of this transformer were so much burnt that it was impossible to discover where the fire had started or what had caused it. It appeared, however, most probable that the transformer had not been thoroughly baked by the 24 hours' warming run it had had, and that moisture from it had condensed

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on some of the terminal arrangements, finally dripping on to one of the high-tension coils, short-circuiting a portion of one of them. On consultation with the manager of the Ivy mine, who pointed out that it was much more important to him to get the hoist going again (as he relied on it to keep his mine dry) than to start the mill, it was decided to attempt to run the hoist motor from the mill transformer, as being quicker than replacing the damaged coils. For this purpose a low-tension current (about 200 volts) had to be transmitted over 550 yards of wire intended to be used for 10,000 volts. By running up the line voltage to about 13,000 volts it was found practicable to counteract to some extent the loss on this low-tension transmission, and the hoist was accordingly got to work again under these conditions by mid-day of the 2nd September. The damaged coils were meanwhile removed and replaced by spare coils. By the 4th September the hoist was again being run by its own transformer, and the mill was started satisfactorily. For a month from this time everything went very smoothly; no thunderstorms occurred, and most of the Author's attention was devoted to the arrangement for governing the speed of the generators, which was giving some trouble.

Regulation of Pelton Wheels.—At first the Pelton Company's original arrangement of automatically deflecting the nozzles by a differential gear was adhered to. At starting, while everything was new, this gear worked very satisfactorily, but after a short time it was found that the sand and mud in the river water increased the friction in the flexible joint, through which the nozzle was attached to the pipe line, to such an extent that the small governing Pelton wheel (which had to supply the power required to deflect the nozzle when quickening the speed, while the large wheel did the work when slowing down was necessary) was quite incapable of performing the work required of it. Mr. Wilms suggested the use of one of the motor-starting water-resistance switches, arranged as an artificial load to be worked by the differential gear, so that the load, and therefore the speed, should be kept constant. Upon trial it was found that one of these water-resistance switches, occupying a floor space of only 15 inches by 12 inches, and about 2 feet in height, was capable of absorbing at least 30 HP. One was therefore put down and connected to the differential gear, so that as load was taken off and the Pelton wheel accordingly tended to run away, resistance was automatically put in, in parallel with the outside load on the 200-volt generator circuit. This arrangement was found to work perfectly; it very

greatly reduced the work put upon the small governor Pelton wheel, so that its speed remained fairly constant; besides keeping the real load on the generator constant, it also kept the generator current steady, and so reduced the variations due to armature reaction, which at high loads on an inductor type of machine is very heavy; thus not only the speed, but also the voltage, remained fairly uniform. It was ascertained that this apparatus reduced speed variations to within 2 per cent., and voltage variations to about the same figure, although the outside load at first, with only the Ivy mill and hoist running, showed alterations of over 40 per cent. every time the hoist was started. The load was, of course, at all times that of the maximum demand, but in the absence of any storage of water, this did not constitute any objection to the arrangement.

Protection against Lightning.—At the beginning of October about a month after starting, the thunderstorms returned. On 4th October a line breakdown occurred while a thunderstorm was going on. By this time the temporary telephone service had been discontinued, as it appeared to be no longer necessary. Evidence, however, that something had gone wrong was obtained from the fact that every portion of the low-tension generating plant (which was insulated from earth by about $\frac{3}{4}$ inch of vulcanized fibre) as well as all insulated metal-work, such as an overhead travelling crane on a wooden gantry, was found to be capable of giving static shocks when touched by anyone standing on earth. At first these shocks caused some alarm, as it was feared that they proved the existence of leakage from the high-tension to the low-tension coils of the transformers, but there is every reason now to suppose that they were merely static, and due to what becomes practically a displacement of the neutral point of the system. On this occasion, which was the first breakdown since the telephones were abandoned, the plant was shut down as soon as it became certain that something was wrong. Kaffirs were sent along the line to look for broken insulators or other apparent damage while the transformers were being examined. The latter proved to be unaffected, but the natives reported that they had found on the line two broken insulators. One of these was found about 4 miles from the generating station, and the other between the Ivy mill and the hoist, about 7 miles from the station. Both points of damage were found to be within 100 yards of a line lightning arrester, and doubts were entertained as to the efficacy of the latter. In each case the head of the insulator was blown off, as usually happened in cases of breakage by lightning; arcs had

then passed over the broken earthenware to the insulator bolt, and thence the current had gone by way of the wooden arm to the pole, and so through the earth-wire to the second broken insulator. One of the wooden arms was completely burnt off, and the other was so badly burnt as to necessitate its being replaced.

In the morning of the 6th October, during another thunderstorm, indications of a breakdown again appeared. This time an insulator had gone, about 6 miles from the generating station, and the arm was burnt as on the previous occasion. The point of damage was again within 100 yards of a lightning arrester. In addition, the transformer at the hoist had also broken down. The current induced by the lightning in the outside wire had passed without doing any harm through a considerable portion of the high-tension winding, and had there jumped through about an inch of air-space to the low-tension coil. Where it got to from here was never found out, as there was no earth to be discovered on the low-tension circuit. At the same time the fact of the wooden arm on the line being badly burnt seems to indicate that there must have been a second earth existing for some time before the breakdown was discovered.

It was noticeable in the transformer breakdown that the discharge current passed round 1,200 turns of the high-tension coil before jumping to the low-tension coil, whereas it could have got through by jumping the same air-space before passing round any of the high-tension turns. This seems to show the fallacy of relying upon choking coils for protecting electrical plant connected with lines subjected to the action of lightning. The mere passing of the lightning-spark did very little damage in itself to the transformer, and does not appear to have been followed by the current produced by the dynamos. Unfortunately, however, the cotton insulation on the coils was set on fire, with the result that one high-tension and one low-tension coil had to be taken out and replaced. This breakdown was a very serious one, as it entailed 26 hours' stoppage of the whole plant, and then a stoppage for about 4 days of either the mill or the hoist, the two being run alternately from the mill transformer, as arranged at the previous breakdown of the hoist transformer. It was apparent that the stoppage would not have lasted nearly so long if the coils had been immersed in oil, as no fire could then have occurred, and perhaps even the lightning would not have broken through. Oil was accordingly put into one transformer of the two under currents at the generating station, as well as into those at the Ivy mill and hoist.

By this time it was clear to the contractors' engineer, Mr. Wilms, and to the Author, that the lightning-arresters in use were not to be depended upon: all three line breakdowns had occurred at points less than 100 yards distant from the nearest arrester, and therefore considerably less than the average distance of all the poles from their nearest arresters, since, it having been discovered that certain points of the line were specially liable to lightning damage, such points had been selected as those at which to apply the arresters. The new observations showed that the dangerous points remained the same, but they further proved that the arresters were incapable of protecting the line for a distance of 100 yards. It was therefore concluded that some new form of arrester should be found, and that pending experiments the plant should be shut down whenever it could be seen from the generating station that thunderstorms were taking place in proximity to the line. Stoppages on this account alone amounted during the rest of October, 1897, to about 30 hours. In addition to these precautionary stoppages two more line breakdowns occurred during the month; one of these was on the 22nd, when an insulator broke and an arm was burnt at 2 miles from the generating station, while the second earth was found to have taken place at the end pole on the line, namely, that immediately adjacent to the hoist transformer and 7½ miles from the generating station. This second earth was due to an arc having passed over one of the arresters, half of these having meanwhile been short-circuited, as it was evident that the original sparking-gap was too large to afford the desired protection. The arc here had evidently been maintained long enough to almost short-circuit the remaining half, as the arrester when taken down was still very hot and the wooden arm upon which it was placed was badly burnt.

After the 8th October, 1897, it was resolved to try a form of arrester which had been recently introduced by Messrs. Siemens and Halske of Berlin. In principle this was similar to the old and well-known horn arrester of the American Thomson-Houston Company, but the application of the idea was much simpler. The arrester consists of two copper bars, bent approximately to the form of half hyperbolas. The vertices of the two hyperbolas are brought to within a short distance of each other, the space between them constituting the sparking gap. One rod is connected to the line and the other to earth, and the two are supported on insulators and placed in a vertical plane opposite to each other and with their axes horizontal. When the difference of potential between the two copper bars becomes sufficient to cause a spark to

leap across, the arc is at first maintained by the dynamo current. The heat of the arc causes it to start rising, and this tendency is increased by the repellent action of the current in the two fixed curved bars on the movable current in the arc. A trial set of the new arresters was made, with an adjustable sparking distance; the vertical height of the copper horns was about 16 inches, and the horizontal distance between their tips was about the same. The sparking space was at first set at three-eighths of an inch, and towards the end of October, 1897, the experimental arresters were fixed on the lines in the transformer house at the generating station. A small piece of tin-foil was then tied to a piece of cotton about 6 feet long, the other end of which was fixed to a stick. With the tin-foil, manipulated by means of the stick, the horns of the arrester were short-circuited whilst the plant was running with the load on. At first a spark apparently only static was produced, but after two or three attempts a dynamic arc started on two of the arresters simultaneously, one being the short-circuited one. The arcs thus formed rushed with a roar upwards, extinguishing themselves before reaching the tops of the horns. Numerous trials produced only the same results; the arcs never lasted more than about a second, and always went out without blowing the fuses or causing any of the load to be lost.

The preliminary tests with respect to sparking distance seemed to show that 10,000 volts will not jump across more than $\frac{1}{4}$ inch of air space, yet on the lightning arresters, as described, two or three attempts at short-circuiting one air-space always caused the 10,000 volts to leap across the $\frac{3}{8}$-inch gap on one of the other two arresters. The Author has not been able to arrive at a satisfactory explanation of this fact. The practical result of these experiments having apparently proved that these arresters with a spark-gap of $\frac{3}{8}$-inch were capable of satisfactorily extinguishing an arc formed on them, orders were given for the making of a number, which were fixed to the lines whenever a stoppage could be arranged for on Sundays, the old ones being taken down as the new ones were fixed. During December, 1897, and January, 1898, thunderstorms took place with the usual frequency and severity, but no stoppage whatever was occasioned by them. In the same months a branch line was constructed from the Ivy mill transformer-house to the Woodbine mine, about $\frac{3}{4}$ mile further on. At this point a transformer was put down, and a 50-HP. motor was connected to it for driving an air-compressor.

Regulation of Motor.—The motor was set to drive through a belt

on to a countershaft, whence the compressor flywheel was driven by means of ropes. The flywheel weighed 5 tons, and consequently the motor had considerable difficulty in getting it into motion. At starting (with no useful load) it took considerably more kilowatts than it absorbed at full load. Moreover, the heavy current taken under such conditions was out of phase with the volts, and consequently its demagnetizing effect on the generators was intensified. The result was that every time the compressor was started, and at first stops and starts were fairly frequent, the line voltage was so reduced that the other motors on the system were stopped, and complaints were very naturally made. A satisfactory solution of the difficulty was found by opening the low-tension neutral of the transformer at the compressor, and by carrying separate cables from each end of each low-tension coil to the motor-room, and there connecting them to a pair of three-pole switches interlocked with one another so that when the one was "on" the other must be "off," and *vice versâ*, it being impossible for both to be on together. From these switches the leads were carried to the motor switchboard. This device acted very well, the strain at starting being apparently relieved to the extent of quite one-half.

Working.—Between the 21st March, 1898, and the present (3rd November, 1898) no real breakdown on the line has taken place. The nearest approach to such an occurrence happened on the 17th August, when it was found that owing to the shrinking of the wooden arms during the dry weather they had become loose on one of the poles, and the ground-level at that pole happening to be much lower than that at each of the adjacent poles, the upward pull of the wires had caused the arms to slide up and partly off the pole till they were stopped by the earth-wire at the top. The plant was running satisfactorily at the time this discovery was made, but a short stoppage was at once arranged to put matters right, as it was feared that a high wind might at any moment cause a breakdown.

A branch line had during this time been taken from the Woodbine compressor line to the same company's mill, which was in process of erection. This was a twenty-stamp mill, each stamp weighing 1,350 lbs., and therefore nearly half as heavy again as any of the mills which had been previously driven by the electrical plant. Estimates of the power required to drive it have proved correct to within 2 per cent. The manager of the company put down two motors for the mill, each of the same size as that in use at the Ivy mill, and obtained from the contractors for Moodie's

Company's plant, Messrs. Rennert and Lenz. During the interval that had elapsed since Moodie's plant was supplied, the Allgemeine Elektricitäts Gesellschaft, of Berlin, for whom Messrs. Rennert and Lenz acted as agents, had somewhat modified their standard pattern for these motors. The alterations resulted in an increase of their full-load output by about 20 per cent., and, which was more important, an enormously increased capability of starting against a load. The latter advantage was gained by inserting the starting-switch in the rotor- instead of in the stator-circuit, as had been also done in the case of the motor supplied for the Ivy hoist. The rotors had to be provided with three collecting rings and a set of brushes for the purpose, but as they were also fitted with a short-circuiting arrangement to be applied when full speed was attained, the collecting rings and brushes were subjected to hardly any wear, being thrown out of contact after the short-circuiting ring was put in. The superiority of these new motors in starting against a load was so pronounced that the Author considers it greatly to be regretted that the attempt was ever made to build polyphase motors with permanently short-circuited rotors.

On the termination of the period of the contractor's guarantee, the plant was finally taken over by Moodie's Company. The remaining two generators (two being just fully loaded by the output at the time) had been erected, as well as the second pair of generating-station transformers, and all had been satisfactorily baked and given trial runs, as well as having the working load put upon them at odd times for a day or two. Throughout the whole period of the guarantee there had been no electrical breakdown on a generator and only a trifling one on a motor. One of the motor-end transformers had broken down twice, the first time being within two days of starting and the second time during the first really severe thunderstorm the plant experienced, about a month after starting, and therefore before the application of the new form of arresters. The line had broken down seven times in all, five failures occurring in the first two months when the old arresters were solely being depended upon, and the remaining two in February and March respectively, on a line started in February. In spite of the conditions under which the new plant was run being much more severe than those which obtained while the old plant was at work, the running time on the new system shows a great improvement over that on the old.

Perhaps the most valuable experience gained during over four years' work in a tropical and mountainous country is that in connection with lightning, which threatened at one time to prove

an almost insurmountable difficulty in long-distance transmission. It may be well, therefore, to collect those particulars which appear to be of value. In the first place, much information was gained from the original plant, although no attempt was made to run it through storms. While putting up the line it was found that the wires, for some hours previous to thunder becoming audible, were capable of giving more or less severe shocks to a man at work on them. As the storm arrived within four or five miles of any part of the line these shocks usually became dangerous to anyone working at the top of a pole, on account of the danger of falling. Temporarily earthing the wires being worked on did not altogether do away with these shocks. As already mentioned, an uninsulated wire was carried from pole to pole above the level of the power wires, and was, at suitable places, connected to a really good earth, such, for instance, as the water-pipes at the generating station. Certain points on the line proved to be specially liable to damage, and these points were by no means always the highest part of the neighbouring portions of the line. This fact was repeatedly brought to notice during the running of the old plant, and in consequence these dangerous spots were chosen as places at which the line arresters for the new system were to be located. Nearly all of the early line breakdowns, after the new plant was started, were at practically these same points, thus justifying the previous conclusions, besides showing that the line arresters were of very little use. The Author has not been able to arrive at any satisfactory theory to account for the existence of these dangerous points, and would like to know whether similar experiences in regard to them have been met with elsewhere. One important fact was clearly proved on the old line, namely, that an absolutely satisfactory arrester at each end of a long line will not protect the middle of it. The old power lines were guarded at the ends only, by "Keystone" arresters, depending on the expansion of air through heating by the arc to drive apart carbon pencils connected respectively to the line and to earth. During nearly every severe thunderstorm, and simultaneously with the lightning, these arresters were seen to go off violently, a flash of flame being observed at the moment when the swinging arms carrying the carbon pencils were driven outwards. As such an occurrence never took place while the machines were running, the flashes must have been solely due to the lightning, whether arising by dynamic induction therefrom or from the sudden alteration in static difference of potential between the line and earth. The spark gap to earth, in the arresters, was a little over $\frac{3}{32}$ inch on the 3,000-volt

line and about $\frac{1}{16}$ inch on the 600-volt lines. It is probable, therefore, that numerous discharges took place through them at other times which were not sufficiently violent to drive the arms apart, and so passed unobserved. It seems therefore fair to conclude that these arresters were satisfactory in protecting the ends of a dead line. They were not tried on a live line. They entirely failed to protect the middle of a line $1\frac{1}{4}$ mile in length.

The telephone arresters satisfactorily protected the telephones and bells. These arresters were those known as the Post-Office pattern, and were selected for use on this plant by Sir William Preece in his capacity of consulting engineer for Moodie's Company. The telephones were never taken off the lines in storms and were in operation with the arresters for nearly 3 years. No single case of damage by lightning to either bells or telephones took place. Part of the system had an earth, and part a metallic, return; on both parts, at first, line breakdowns occurred very frequently. These failures of insulators were afterwards entirely stopped by means which will be subsequently described. The only fault which could be found with these arresters was that the discharges through them very frequently raised beads of melted metal on the surfaces of the plates, which extended across the sparking gap and earthed one or both lines. The Author ventures to suggest that perhaps the use of carbon instead of metal plates might prove in practice an improvement in this respect. When the new plant was started, and trouble from lightning was being experienced, one of the bells was connected for purposes of experiment on one side to one of the dead wires and on the other side to earth, no arrester being put in. Half an hour after connecting the bell a thunderstorm came on, and at the first flash which occurred near the line the bell broke down with a noise like a pistol-shot. The wires leading from its terminals to the coils were found to be fused throughout, and an arc had passed through both coils. A bell, therefore, which had lasted nearly three years when protected by these arresters, broke down after half an hour's run when not protected.

The most conclusive, however, of the observations which showed that means of protection on the lines, as well as at the stations, were an absolute necessity, occurred while one of the lines was being put up. One wire, $1\frac{3}{4}$ mile in length, strained and bound to its insulators, terminated at each end in a coil; on a Saturday afternoon, when work was stopped, these coils were placed on the ground leaning against the poles. In the afternoon a storm occurred, and one flash of lightning struck a heap of

stones, about 400 yards distant from the nearest point of the line, this point being about 400 yards from the end of the line. No other flash struck anywhere within a mile of any part of the line, nor was there any rain closer than that distance. Some men sitting close to one end of the line, on which they had stopped work only one or two hours previously, heard a discharge pass from the coil of wire to the pole, making considerable noise. The line was at once examined; it was found that there were distinct marks of an arc having passed between the coils at both ends and the poles against which the coils were leaning, and also that at a point about halfway along the line an insulator had been broken, and marks were here observed of an arc having passed from the wire to the earthed insulator-bolt. In this instance, therefore, the presence of a dead earth at each end of a line $1\frac{3}{4}$ mile long was not sufficient to protect the middle.

Another hint gained from the running of the old plant was in connection with the frequency at first of failures of insulators on the telephone lines. The wires for these were underneath, and parallel to, the power wires on the same poles. It was found that, taking into consideration the proportion between the numbers of telephone- and power-insulators, failures of the former through lightning were about sixty times more frequent than those of the latter. Both sets of insulators were made of the same ware by the same makers, but the patterns and sizes differed. In the case of the power wires the distance from the wire to the earthed insulator-bolt through the earthenware was about $\frac{7}{8}$ inch; on the telephone insulators the corresponding distance was very little over $\frac{1}{4}$ inch. All insulators destroyed by lightning were apparently pierced through the earthenware along the shortest path to the bolt, the shock of this invariably blowing the head off the insulator. It was concluded that the much higher frequency of breakdown of the telephone insulators could be due to nothing but the thinness of the earthenware, and the Author believes that this is important, not only in connection with lightning, but also in designing plant to run at high voltage.

The trouble on the telephone lines was overcome by very simple means. After the first few storms, whenever an insulator broke and a new one was being put in its place, one end of the binding wire used to attach the line to it was left a few inches longer than usual and was bent down and round so that its extremity came to within $\frac{1}{8}$ inch of the insulator bolt. After these short spark gaps had been fitted to about every tenth pole there was hardly any other case of a telephone insulator breaking down.

Examination of any of these wire-ends which had been in place through a few thunderstorms showed that almost all of them had discharged at one time or another. The ends of the wires were often found fused into a ball of quite $\frac{1}{8}$ inch in diameter, which gives another indication of the amount of heat sometimes developed in these discharges.

The earthing of the generator- and motor-generator-frames on the old plant was probably a mistake. Mr. J. Hubert Davies, when supplying motors for the Ivy and other mills, had strongly advised that the frames should be insulated from earth, and in consequence they were all, with the exception of the motor at the hoist, bolted down to 6-inch timbers, which in their turn were bolted to concrete foundations. As no running was intentionally done with the old plant during storms, little proof was gained of the advantage of insulating the frames from earth, but it may be remarked that all three breakdowns to earth through lightning, on the old machines, occurred at the earthed frames at the distributing station. At any rate, in putting down the new plant it was decided to insulate the transformer-frames from earth by about 6 inches of timber. All the motors, except that at the hoist, were also insulated from earth with wood, and the generators were placed on vulcanised fibre, about $\frac{3}{4}$ inch thick. The high-tension coils in the transformers were nearly 1 inch away from the nearest part of the low-tension circuit, and the low-tension coils were about the same distance from the cores. These 1-inch spaces were intended to be, and ultimately were, filled with resin oil. Leaving the line out of consideration for the moment, the weakest point of the high-tension system was clearly the hoist transformer, as the motor connected to its low-tension coils had an earthed frame. It is noteworthy that the only breakdown of a transformer from lightning happened at this point, though no trace of the passage of any discharge from the low-tension circuit to earth was ever found.

Comparing generally the relative suitability of the two systems, namely, continuous current with motor-generators, and three-phase alternating current with stationary transformers, for an undertaking like that described in the foregoing, the new plant was, on the whole, a vast improvement on the old. Its most conspicuous advantages were:—

1. The saleable output from a given quantity of water was increased by about 50 per cent. This result, as previously pointed out, arose, not from the use of the three-phase system, but solely from the increased voltage employed and the abandonment of the

distributing station. This increased output of power also brought about indirect advantages to Moodie's Gold Mining and Exploration Company, Limited, by increasing the value of the percentage royalty on gold won, which was obtained from the Company's lessees.

2. The staff and other expenses were reduced by 50 per cent. when the distributing station was rendered unnecessary. The new plant is being run by three white men, two of whom each take six 12-hour shifts per week. The third man has charge of the station, and takes the other two shifts to make up the 7-days' run; he also does any repair work which may be required, supervises stores, etc. In order to make sure of getting safely through the fever season, one or two other men, resident in the neighbourhood, whose ordinary work is of an intermittent nature, are being instructed in the method of running the plant with the view of making them available if more than one of the permanent staff happen to be laid up at one time. During the last fever season, which was rather a severe one, three men out of five (erection work being then in progress) were invalided at one time. Without taking into account the indirect advantage referred to, it will be seen that, by the change in system, the ratio of receipts to expenditure had been made about three times as great as that which had at first obtained.

3. Running through thunderstorms was rendered possible, resulting in an average gain in running time of over 14 hours per month. No attempt having been made to run the old plant through storms, the material available for contrasting the two systems is somewhat scanty. The Author's own opinion, however, is that it is much easier to protect high-tension than low-tension plant, and alternating-current than continuous-current machines. This largely arises from the fact that it is much simpler to arrange for a high insulation on a stationary transformer than on a rotating machine. Amongst other means, the coils of a transformer can be immersed in oil, which cannot be done with a dynamo. In this connection the Author considers it a great mistake to put down generators to deliver current at the high-tension line-voltage where there is any danger from lightning. In such cases he considers that a transformer will always soon pay for itself.

4. The unsatisfactory telephone service was rendered superfluous, so far as regards the running of the machines. Its entire suppression, however, has rendered the work of supervision considerably more arduous.

5. About 15 tons of copper wire, rendered unnecessary, were

taken down from the old lines, and are now available either for extensions or for sale.

6. The windings of the three-phase motors and generators seemed less liable to breakdown than those of the continuous-current machines. This was no doubt partly due to the three-phase windings being carried through holes or slots in the iron, instead of being laid on the surface, as in the continuous-current machines used on Moodie's original plant, so that the wires of the former experienced no racking effect and required no binding-wires. The low voltage (200 volts) used on generators and motors no doubt also helped, as well as the absence of commutators, which are of course much more liable to cause trouble than are collecting rings.

7. The switchboard arrangements throughout were extremely simple, more particularly at the motor ends, where the use of a liquid-resistance as a starting-switch proved very convenient and gave no trouble.

8. The motor speeds remained practically constant so long as the number of cycles per second, dependent solely on the speed of the generators, was kept steady. The speed of the motors at full load was only 5 per cent. lower than the speed of their fields, and of course was never quite equal to the latter, even with no load, so that the maximum speed variation between full load and no load only reached about 4 per cent. In this respect the new motors were about equal to the best shunt-wound continuous-current motors, but they had the advantage over the latter of running at speeds independent of the voltage they received. Consequently, so long as the generators were kept running at a steady pace the taking-off or putting-on of any one motor had no effect whatever on the speed of any other. On a continuous-current system the taking-off of a motor would have the effect of raising the voltage on all others that were dependent for their current supply on the same wires, with the result that their speed would be raised and adjustment would have to be made by cutting resistance out of the shunt circuit. In the old plant this effect was guarded against by allotting separate wires from the distributing station to every motor. Further means which had to be adopted to keep the speed and the voltage steady was, in the case of the hoist motor, the automatic insertion of an equivalent resistance whenever the motor was switched off. With all other motors, notice of intended alteration in the load had to be signalled down to the generating station by telephone before the alteration took place. This only enabled the pressure at the distributing station to be

kept steady; therefore, in addition, the position of the motor regulating-switch had to be adjusted for every change of load. All this was done away with on the new system.

In some respects the constancy of the motor speeds might be in the nature of a disadvantage. In the first place the sizes of the pulleys had to be very carefully attended to, having regard to the proportion of their full load which would ordinarily be put upon the motors. Then it was by no means convenient to slow down any particular motor, even temporarily, for any reason. The only way this could be done was by inserting resistance in the rotor circuit by means of the starting switch, which resulted in the boiling away of a quantity of water, and lowered the efficiency of the motor. In the case of Moodie's Company's plant, this loss of efficiency was of little consequence, as there was no means of storing the water, and charges to consumers were based upon their maximum demands, no allowance being made when the full power was not being used. On other plants, however, it might be a serious matter when variations of speed are required.

Perhaps the strongest objection to the three-phase system, as applied at Moodie's, lies in the difficulty of starting the motors. The first of these which was installed, not being provided with collecting rings, started very badly, even with no load on. The alteration of the transformer connections, so that they could be used temporarily, while starting, as a triangle- instead of a star-combination, made a great improvement, but the insertion of a resistance into the rotor-circuit by the help of collecting rings, as arranged on the later motors purchased, is undoubtedly the best solution up to the present. These later motors started quite easily against a light load. It was fortunate that on Moodie's plant the capability of starting was not of very great importance, as almost all the machines were required to run continuously, so that starts were not as a rule of frequent occurrence.

The Author considers the use of wooden arms to be a mistake They are, however, not an essential point of a three-phase high-tension system, although the contractors, following American practice, insisted on their use. The idea that they raise the insulation resistance of a line is altogether delusive. At times when the insulation resistance of the insulators is at its worst, namely, during wet weather, the use of wooden, instead of iron, arms on iron poles makes hardly any appreciable increase in the line insulation. A discharge which is able to pierce an inch of glazed earthenware would probably very easily pass over a few inches of wet wood. The one advantage attendant on their use is that in the

case of an insulator becoming perforated, without being damaged to such an extent as to render the breakdown evident from the ground, the wooden arm, by becoming charred, serves to call attention to the failure of the insulator. The proper course, however, seems to be to get insulators that do not break rather than to look for means of finding them when they do. On the other hand, the life of a wooden arm cannot be compared with that of an iron one, and in a tropical country cannot be put down at longer than 3 years, even when supported upon an iron pole. Further mechanical disadvantages of wooden arms are obvious. They split, warp, and shrink, all of which tendencies help to break down a line. Moreover, the burning off of an arm may cause a wire to fall down so low—if no guards are provided—that it may come into contact with a passer-by on horseback or on foot. This danger is very much accentuated at the end poles of a line. Any failure of the wooden arm here lets the wire down for possibly several hundred yards from it. This consideration led the Author, soon after starting, to put iron arms at these terminal poles, and to connect the wires on to shackle insulators instead of to those of the ordinary type. To increase the electrical strength of the ordinary shackle, three of them were put in series. At the worst, if all three shackles are broken by a discharge to earth, the particular wire becomes a dead earth; but unless it fuses through it can only draw back an inch or two, instead of being liberated altogether, as it would if either the ordinary insulator or a wooden arm were used.

The Author is glad to be able to say that no serious accident to persons has ever occurred on the plant. One man received a shock from the line to earth, but was able to resume work within half an hour. He was working in a transformer room, in close proximity to live wires and a set of arresters. A discharge suddenly occurring on the latter, he started, and his hand came into contact with a wire. It is probable that the wire he touched was one of those which at the moment were arcing to earth, so that the man's body was in parallel with one arrester arc, and in series with another across the 10,000-volt lines, and he was not standing on a good earth. Shortly after this narrow escape all the sets of arresters which had been placed in motor-transformer rooms were removed to positions just outside, so that a similar accident can never again take place from the same cause.

The Paper is accompanied by ten photographs, illustrating the Plants described and the general nature of the country referred to.

(*Students' Paper 436.*)

"Turbines."[1]

By Arthur Henry Tyack, Stud. Inst. C.E.

A Turbine, as distinguished from the old water-wheel, may be defined as a water-wheel in which motion of the water relative to the buckets is essential to its working. Turbines are classed according to the way in which the water acts, as (1) reaction wheels, and (2) impulse wheels.

The curves of the buckets and guides of a reaction wheel are shown diagrammatically and in cross section in *Figs. 1.* The path

Figs. 1.

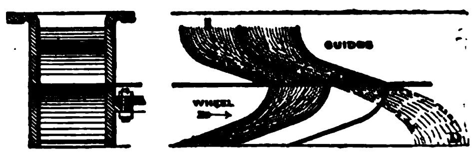


Diagram of Buckets and Guides of Reaction Wheel.

Figs. 2.

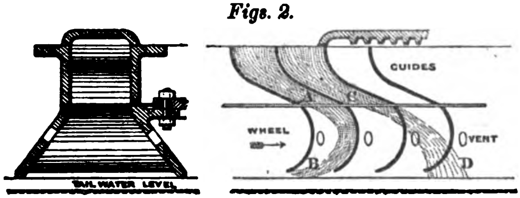


Diagram of Buckets and Guides of Impulse Wheel.

of the water relative to the wheel-buckets is indicated at AB, and the actual or absolute path relative to the earth, when the wheel is in motion, is shown at CD. The curves of the guides and buckets of an impulse wheel are shown in a similar manner in *Figs. 2.* It

[1] This Paper was read and discussed at a meeting of the Manchester Association of Students of the Institution on the 14th December, 1898.

will be noticed that in this case the curves are so formed as to offer the least resistance to the flow of the incoming water, which glides along the concave surface without filling the buckets, thus acting entirely by impulse. The inflow of water must take place under atmospheric pressure only; to ensure this end, and to prevent the formation of eddies in the empty spaces behind the jets, the buckets are ventilated.

Reaction Wheels.—These are particularly suited for low falls with large volumes of water, but they may be designed to work with comparatively small volumes. A reaction wheel may work drowned, *i.e.*, surrounded by its tail-water, or a suction pipe may be used, in which case the turbine can be placed at a height of 25 feet to 30 feet above the tail-water, without losing any working head. The maximum height theoretically is 34 feet, but in practice the height varies with the diameter of the tube, and should not exceed 25 feet. It is always advisable to use a suction tube if possible, as thereby the wheel and footstep can be inspected at any time, without the labour of pumping the well dry, as is necessary when the wheel is submerged in the tail-water. Each of the two classes of wheels may be again divided into three subdivisions, according to the direction in which the water flows through the wheel, namely, radial-flow, parallel- or axial-flow, and combined- or mixed-flow.

The Fourneyron turbine is an example of a radial outward-flow wheel. The water enters a cylindrical feeder with a vertical or downward flow, and is deflected outwards by guides, which direct it into the buckets constituting an outer ring, connected to the shaft. In 1834 Fourneyron constructed a wheel of this description, developing 8 HP. under a fall of 9 inches, and a few years later he built one, having a diameter of 13 inches, which developed 120 HP. under a fall of 354 feet, running at 2,300 revolutions per minute. These instances will serve to show under what a variety of conditions a turbine may be employed. A disadvantage of this type of turbine is that it cannot be used with a suction tube, but by reversing the flow, *i.e.*, allowing the water to flow inwards, and having the guides on the outer ring, this difficulty is obviated, and moreover, inward-flow wheels do not use as much water as outward-flow wheels.

Inward-flow wheels show a high efficiency at "full gate," but in all reaction turbines the efficiency is materially diminished when working at "part gate." Inward-flow as well as outward-flow wheels can be made to accommodate a very varying supply, by building two or three distinct turbines, one above another and

all keyed on the same shaft. By means of a cylindrical gate, the water can be shut out from any wheel, thus controlling the volume of water used, the important condition with all reaction turbines being that the wheel and guides should be entirely full of water. This form of construction, of course, is more costly than the simple wheel. The vortex turbine is a variety of the inward radial-flow type, and was invented by the late Professor James Thomson. In this turbine the buckets are exceedingly numerous and very small, while there are only a few guides. The turbine is built in one or two layers, constituting a single or a double vortex turbine respectively, but in the latter the water has always free access to both divisions, the regulation being effected in a different manner from that employed in the Fourneyron type. The single vortex wheels may be used with a suction tube, but they are more often placed just above the tail-water, in which case the outer covering is dispensed with. Although necessarily larger than the double variety of the same power, they are very suitable for low falls and large volumes of water, but they are not used on a horizontal axis. Double vortex wheels can be placed on a horizontal shaft, thus dispensing with bevel gearing and the usual accompanying frictional loss. The water from each layer discharges at the centre of the wheel, and escapes at each side down a suction tube, and the two divisions of the wheel balance each other, so there is no end thrust on the bearings. These wheels, and also the single type, must be entirely enclosed when used with a suction pipe. The mode of varying the capacity of the wheel to suit the volume of water is peculiar to this design. Bell-crank levers actuate the guides, enlarging or contracting the inlets as desired, thus regulating the supply without any sudden contractions or throttlings, which cause great waste of power. The simple mode of regulating and the compactness of the motor combine to render this a very desirable turbine for medium falls and large volumes of water. For small installations with a variable supply, and where first cost is a greater consideration than a very constant supply of energy, these wheels are very suitable, but in cases where it is necessary to obtain the maximum amount of power from a diminished water-supply it is often advisable to go to a greater first cost, in order to get a motor which will show an equally high efficiency at part and full gate.

The Jonval wheel, being a parallel-flow motor, is particularly suited to subdivision into a number of concentric rings, each representing a complete wheel, from which the water can be

excluded at will. Vertical sections of the guides and buckets of a motor of this class are represented in *Figs. 1.* Jonval turbines are especially suited for low falls and rivers liable to heavy floods, as they are capable of working deeply immersed in the tail-water, and continue to work so long as there is any head whatever. They are adapted for use with a suction tube, but for falls lower than 8 feet the wheel is generally surrounded by the tail-water. Falls of 8 feet to 15 feet may be similarly used, with an open tank above the wheel, or a suction tube may be used for all or part of the fall. For heads exceeding 15 feet the wheel is generally placed well above the tail-water, the water being delivered to the guides through an iron pipe. The maximum fall suited to these wheels is about 50 feet, but they can be and are used on higher falls. The regulation in this type of wheel is obtained by blocking up the spaces between the guides, and so preventing the full amount of water flowing in. From the direction in which the water flows, it follows that axial-flow wheels produce a greater pressure on the footstep-bearing than do radial-flow turbines, and with high falls this pressure would be a serious item if it were not counter-balanced in some way. One method of getting over this difficulty is to invert the wheel, passing the water upwards through it, and to make the boss of the turbine form a piston subjected to the pressure in the pipe or penstock. Another method consists in having two turbines on the same shaft with a space between them, the water acting upwards through the higher one and downwards through the lower one. This plan has been adopted at Niagara in the case of Fourneyron wheels, and it has the additional advantage that the shaft velocity is twice that obtained with only one wheel.

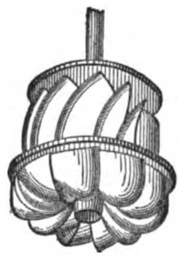
Jonval wheels are much favoured on the Continent for low falls, but the practice of building them up in sections adds considerably to the cost. At Brentwood, in Essex, a wheel of this type is used to drive a flour mill; the fall, being obtained from a tidal river, varies between a maximum of 4 feet 9 inches and nil. From a head of 32 inches 40 HP. is generated, and is maintained for 16 hours out of the 24 hours, while for an additional 6 hours the power obtained from a fall of 1 foot is still utilized. The wheel is 10 feet in diameter, and develops 7 HP. under a fall of 15 inches; there are two concentric rings which are opened and closed to suit the supply, and by this means a constant speed of 30 revolutions per minute is maintained.

At Olten-Aarburg, in Switzerland, six wheels of this description have been installed, working under a fall of 5 feet 6 inches. Each

wheel develops 300 HP. when revolving at 28·5 revolutions per minute, and drives a dynamo direct. This is one of the lowest speeds a dynamo has ever been worked at. Jonval wheels built in three rings are working at the Geneva Waterworks, and give a constant speed, winter and summer, although the head falls from 12 feet in the former period to 5 feet 6 inches in the latter, when the volume is greatest. The outer ring alone can give the maximum HP. under the maximum fall, the other rings being brought into use as the volume increases and the fall diminishes, so maintaining a constant speed of 36 revolutions per minute.

In mixed-flow wheels the water enters radially, is deflected downwards, and escapes either radially outwards or downwards. There are many varieties of this type, generally differing only in small details; one of the best known, certainly in this country, is the Victor turbine. The wheel of a Victor turbine, removed from its case, is shown in *Fig. 3*. The motor is composed of three parts, viz., the outer guide case, inside of which is the register gate, and the wheel proper. The register gate, for regulating the speed by varying the supply, forms a continuation of the guide-passages when open, and does not interfere with the flow of water; but by turning it through a small part of a revolution it blocks, or partially blocks, the passages, and consequently retards the inflow of water. This method of regulation is simple, and is fairly efficient down to three-quarter gate.

Fig. 3.



WHEEL OF VICTOR TURBINE REMOVED FROM ITS CASE.

Mixed-flow wheels are suitable for low and medium falls, up to about 50 feet, where there is a large volume of water to be dealt with under a fairly constant head. These motors are generally placed on a horizontal shaft, working either singly or in pairs; in the latter position they thrust against each other, and prevent end thrust on the bearings. They can be used with a suction tube when working on either a vertical or a horizontal shaft. Victor turbines, with a diameter of 4 feet 9 inches, have been erected for the Lachine Rapids Power Company, U.S.A., each developing 300 HP. from a head of 16 feet, working drowned, and running at 83 revolutions per minute. At Massena, U.S.A., 75,000 HP. is generated under a fall of 40 feet, with fifteen Victor turbines of 5,000 HP. each. The wheels work on vertical shafts, four being placed on each shaft, and they are arranged to work in pairs, the water passing upwards through one and downwards through the other, by which arrangement the great weight of water

is taken off the footstep. In order to get the requisite fall in this instance, a river was diverted through a canal 225 feet wide, 25 feet deep, and 3½ miles long, with a gradient of 6 inches per mile.

There are various devices for regulating the speed of reaction turbines, none of which are very satisfactory. The ideal method is to contract the openings in the guides and in the buckets at the same time, and in the same ratio, but this entails too great complication for practical purposes. One of the simplest, but at the same time one of the worst methods of regulating, is to close the outflow orifice of the suction tube. The volume of water flowing through is certainly diminished, but the velocity is also diminished, and, as the work done is proportional to the square of the velocity, the efficiency decreases in the same ratio. Another method is to curtail the supply by means of a throttle-valve on the inlet; in this case the wheel is not full of water. A better method than either of the foregoing is to close some of the guide passages and so diminish the capacity of the wheel, this method being generally adopted with Jonval wheels. Blocks of wood of the requisite shape are moved, by means of rods reaching to the platform, in such a way as to completely close any of the guide passages. In this mode of regulating it is important to have the guides either wide open or completely shut, and the guides should be worked in pairs, the guides composing a pair being situated diametrically opposite to each other, by which means equilibrium is maintained. Pivoted sluices are sometimes substituted for the blocks of wood, and are manipulated by rods in the same manner, but they are very liable to get choked. In Fourneyron's wheels, the regulation is effected by means of a circular gate which entirely surrounds the outside circumference of the buckets, and which is capable of being raised or lowered as required. This method was adopted on the wheels erected at Niagara, and is especially suitable for a wheel built in several layers. The method of regulation by means of movable guide blades is very simple when there are only a few guides, but with a number it becomes rather complicated. This method, as used in the vortex wheels, is perhaps as good as any, but it is by no means perfect, as the guides can only occupy one position in which they form the correct curve.

The following Table, compiled from experiments made by Mr. J. C. B. Lehmann,[1] shows the relation between the various losses occurring in the different varieties of reaction turbines:—

[1] Minutes of Proceedings Inst. C.E., vol. lvii. p. 412.

Loss due to:	Axial Flow.	Outward Flow.	Radial Flow.
	Per Cent.	Per Cent.	Per Cent.
Hydraulic resistance	12	14	10
Unutilized energy	3	7	6
Shaft friction	3	2	2
Total loss	18	23	18
Efficiency	82	77	82

Impulse Wheels.—In this class of turbine, as the name implies, the water acts entirely by impulse, the wheel working above the tail-water, and the water in the buckets being under atmospheric pressure. A feature of impulse wheels is that they work as efficiently at part supply as with the full volume of water for which the wheel was designed, and on this account alone they are the most suitable motors for medium falls with largely varying volumes of water. Impulse wheels are generally known as Girard turbines, from the name of their inventor, who first introduced the system of ventilated buckets. They are constructed both as inward and outward radial-flow turbines, either on a vertical or a horizontal axis. The Girard wheel cannot be used with a suction tube, but as the footstep is generally placed above the tail-water, it can readily be inspected. For falls up to about 60 feet, a radial inward-flow Girard is best suited, fixed to discharge just above the tail-water. The water is brought to the wheel in iron pipes, and any variation of supply is allowed for by opening or closing some of the guides. For high falls, where the water is limited, a partial injection turbine can be used, whereby the diameter can be increased and the velocity correspondingly decreased, as only a part of the circumference of the wheel is utilized for the water. With excessive heads, the water is generally delivered at the inner circumference and discharged outwards with partial injection, and under these circumstances it is found advisable to enclose the wheel entirely and place it on a horizontal axis. Girard turbines are especially adapted to high falls, but they work equally well under medium and low falls.

The last motor to be described is the Pelton wheel, which is of American origin. In appearance it resembles the ordinary water-wheel, having a number of bifurcated cups or spoons on the circumference, which are curved so that the jet of water striking them is deflected back parallel to its original direction. These wheels invariably work on a horizontal axis, and they are cheap

and easily erected, besides showing a high efficiency. Beyond the lower price and the simplicity of this motor it has no advantage over the Girard type. The greatest efficiency is obtained from a Pelton wheel when it runs at a circumferential velocity equal to half that of the jet of water. It is seldom used for heads of less than 100 feet. Pelton wheels 4 feet 9 inches in diameter are installed at San Joaquin, California, and work under a head of 1,411 feet, which gives a pressure of 610 lbs. per square inch at the nozzle. The water is delivered into a $\frac{3}{4}$-inch steel receiver, 30 inches in diameter, from which it issues through a $\frac{1}{8}$-inch nozzle with a velocity of 1,000 feet per minute, striking the buckets at an angle of 45° with the horizontal. Each wheel generates 500 HP. when running at 600 revolutions per minute.

For very low falls with large volumes of water, a reaction wheel should invariably be chosen, as an impulse turbine must discharge above the tail-water, with a consequent loss of fall, and this is a serious item when the total available fall is small. Reaction wheels will work submerged in the tail-water, and will continue working as long as there is any fall whatever, this feature rendering them the most suitable motors in positions where the tail race is likely to be backed up by floods. Reaction wheels are smaller than impulse wheels of the same power and for the same volume of water, and therefore revolve faster, but when revolving very fast and working submerged, the hydraulic resistance increases; they are, however, as a class, slightly more efficient than the Girard wheels.

The Fourneyron or outward-flow wheel is now seldom adopted, as it cannot be used with a suction tube, while the efficiency is not quite so high as in the other varieties. The vortex wheel is to a certain extent self-governing as to speed, and this fact recommends it to electrical engineers. Two wheels of this class on a horizontal shaft form a compact motor, which can be used under falls which are too high for a Jonval wheel, and where the requisite speed renders a reaction turbine preferable to an impulse turbine. It is especially suited to falls between 40 feet and 150 feet.

The Jonval turbine, when built in concentric sections, is very efficient at part gate, and is the best motor for a low fall, with a variation of volume which continues for a lengthened period, but at the same time it is the most expensive. It is not often adopted for heads exceeding 40 feet. Mixed-flow wheels, as will be seen from the appendix, occupy very little space. Contrary to the usual practice, the American custom is to make these wheels in one casting, of standard dimensions suitable for

the same volume of water under any conditions; hence their low cost. All reaction wheels are deficient at part gate, while impulse turbines work equally well with a full or quarter supply, and for this reason they have been adopted on the Continent for every variety of fall. They are especially adapted for working under a high head with a small volume of water, conditions which would necessitate a small reaction wheel, revolving at an exceedingly high velocity, entailing a great hydraulic frictional resistance; a Girard wheel, however, with partial injection, may be made of any size to produce the desired velocity. Between the several varieties of impulse wheels there is little to choose; inward flow is generally adopted for medium falls, while outward flow with partial injection is the type generally used for high falls. The wheel generally runs on a horizontal axis and is always enclosed.

The Paper is accompanied by two tracings, from which the Figures in the text have been prepared.

APPENDIX.

Comparison, Dimensions, Revolutions, &c., of Turbines.

Fall in Feet.	HP.	Vortex (Reaction).			Jonval (Reaction).			Victor (Reaction).			Girard[2] (Impulse).		
		Volume in Cubic Feet per Minute.	Diameter[1] in Inches.	Revolutions per Minute.	Volume in Cubic Feet per Minute.	Diameter[1] in Inches.	Revolutions per Minute.	Volume in Cubic Feet per Minute.	Diameter in Inches.	Revolutions per Minute.	Volume in Cubic Feet per Minute.	Diameter in Inches.	Revolutions per Minute.
5	5	..	..	..	..	..	..	682	15·0	162	..	..	..
..	10	1,412	82	50	..	..	..	1,338	21·0	134	..	..	..
..	30	4,236	131	27	..	..	..	3,800	44·0	60	..	..	..
..	40	5,648	144	25	..	..	..	5,182	55·0	50	..	..	..
10	5	353	69	174	390	21	187	314	10·0	383	..	..	..
..	10	706	102	121	728	27	139	735	15·0	259	..	..	..
..	20	1,412	118	87	..	..	..	1,245	20·0	193	..	..	..
..	40	..	..	..	..	..	..	2,532	30·0	129	..	..	..
..	60	..	..	..	..	..	..	3,751	35·0	111	..	..	..
20	5	176	49	360	185	15	427	179	6·0	935	..	..	..
..	10	353	65	275	355	18	320	310	8·0	690	366	24	150
..	20	706	90	185	734	24	228	646	12·0	441	729	27	135
..	30	1,060	102	174	1,040	27	197	944	15·0	340	1,080	30	133
..	100	..	..	..	..	..	..	3,100	27·5	201	..	..	..
..	200	..	..	..	..	..	..	6,400	40·0	132	..	..	..
..	300	..	..	..	..	..	..	9,100	55·0	99	..	..	..
30	5	118	42	520	120	12	600	..	..	..	..	..	..
..	10	236	54	425	252	15	440	220	6·0	1,113	..	..	..
..	20	471	69	300	480	18	390	430	10·0	670	473	27	172

..	40	941	90	230	947	24	278	791	12·0	540	943	30	156
..	50	1,176	102	210	1,177	27	227	1,042	15·0	400	1,165	36	120
..	100	2,068	112	150	..	..	..	2,157	20·0	385	2,300	48	96
..	200	..	..	..	..	..	..	4,150	30·0	228	..	..	..
..	300	..	..	..	..	..	..	6,492	35·0	191	..	..	..
40	10	176	49	510	177	12	750	..	..	..	..	..	..
..	20	353	65	394	356	15	562	354	8·0	969	358	24	210
..	30	530	69	347	557	18	450	..	..	..	549	27	199
..	40	706	82	292	707	21	370	626	10·0	772	..	..	..
..	50	883	90	270	884	24	360	800	12·0	601	..	..	..
..	100	1,765	110	220	..	..	..	1,560	15·0	508	1,762	36	160
..	200	..	..	..	..	..	..	3,146	22·5	348	3,400	48	120
..	300	..	..	..	..	..	..	4,951	30·0	271	..	..	..
60	10	118	46	662	..	..	..	..	..	..	133	25	210
..	20	235	54	600	..	..	..	..	..	..	250	30	145
..	50	588	69	354	..	..	..	..	..	..	..	..	..
..	100	1,176	102	298	..	..	..	..	..	..	..	..	..
100	5	35	36	1,442	..	..	..	..	..	..	35	10	720
..	10	71	42	960	..	..	..	..	..	..	74	15	488
..	30	212	51	680	..	..	..	..	..	..	215	30	280
..	50	353	65	629	..	..	..	..	..	..	358	36	235
200	15	..	..	..	..	..	..	..	..	..	55	18	585
..	20	..	..	..	..	..	..	..	..	..	72	20	540
..	50	..	..	..	..	..	..	..	..	..	170	25	446
300	20	..	..	..	..	..	..	..	..	..	47	30	432
..	30	..	..	..	..	..	..	..	..	..	70	30	432
..	75	..	..	..	..	..	..	..	..	..	173	30	432
..	100	..	..	..	..	..	..	..	..	..	230	30	432

Efficiency 75 per cent. to 86 per cent.

[1] Diameter of Vortex and Jonval wheels measured to the outside of the guides.

[2] Girards for falls exceeding 50 feet are considered as partial injection motors.

(*Students' Paper No. 447.*)

"The Propelling Machinery of a Torpedo-boat Destroyer."[1]

By William David Seton Brown, Stud. Inst. C.E.

Although the torpedo-boat has ceased to be a novelty, and a speed of 30 knots per hour is regarded with indifference, a few particulars of the machinery by which this speed is attained, and of improvements suggested by recent experience, may prove of some interest. The Author proposes to confine himself to the propelling machinery of the enlarged torpedo-boat known as the "destroyer."

Boilers.—The most characteristic feature of these vessels is the boiler. With the exception of H.M.S. "Havock," "Hasty," "Dasher," and "Charger," which were fitted with the locomotive-type marine boiler, all our destroyers owe their speed chiefly to what is known as the express, or small-tube water-tube boiler. The locomotive boiler which was for a long time the standard boiler for small craft had been pushed to its utmost limit; at high powers its limited grate area had to be compensated for by a high rate of combustion, to which it was not suited, and leakage at the tube-ends was frequently the result. The express boiler, however, presents conditions exactly the reverse. Apart from its superiority in point of weight, its ample grate area has obviated the necessity for such high rates of combustion, though its rapid circulation and unexposed tube ends enable it to stand the most severe forcing, should occasion demand it. Several vessels of the torpedo-gunboat class and a third-class cruiser are having their locomotive boilers removed and water-tube boilers substituted; in fact the locomotive-type marine boiler may be said to be obsolete. The types of express boiler chosen for H.M. 27-knot destroyers were the "Thornycroft," "Yarrow," "Normand," "Blechynden," "Reed" and "White." They all consist of an upper drum, forming the steam space ("White's" boiler has two upper drums) con-

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[1] This Paper was read and discussed at a meeting of the Newcastle Association of Students of the Institution on the 23rd March, 1899.

nected to lower drums, or water pockets, by a number of small tubes forming the heating surface, and, with the exception of the Yarrow boiler, by a few large pipes, commonly called "down-comers," forming passages for the downward flow of water. The grate occupies the space between the lower drums, and the products of combustion impinge on the small tubes on their way to the smoke-box.

The tubes for these boilers are now invariably of solid-drawn steel, generally 1 inch to $1\frac{1}{4}$ inch in diameter and $\frac{3}{32}$ inch thick. Some of the earlier destroyers had copper tubes, but they proved unreliable, and have been replaced by steel tubes. Copper loses its strength at high temperatures to such an extent as to render it unfit for the tubes of high-pressure water-tube boilers. Tubes are galvanized externally to reduce external corrosion from damp when lying up. They are cleared of soot when under steam by a jet of steam from a portable nozzle connected by a flexible pipe. Air-tight doors are provided in the casing for this purpose. With the exception of those of the Reed boiler, the tubes are expanded into their drums or tube-plates, the friction of the tube joints being sufficient to prevent the drums being blown apart by the pressure on the areas opposite the tube ends. The curved tubes used in these boilers do not exhibit any tendency to straighten under pressure as might be supposed, while straight tubes generally acquire a slight curvature. The necessity of expanding tubes into very small drums led to the invention of the Thornycroft tube expander, which is turned and fed through bevelled gearing by a shaft long enough to reach the whole length of the drum. The fire-boxes are lined at their ends with fire-brick, and the lower drums at each side of the grate are also protected with the same material. The casing usually consists of two thicknesses of $\frac{1}{16}$-inch sheet steel with asbestos cloth between. The fire-bars are of wrought bar-iron lightened by numerous holes and riveted in pairs with distance-pieces between.

Considering generally the elements which make for efficiency in boilers of this type, the most important is rapid circulation. Circulation of some sort is absolutely essential to prevent the tubes overheating at high rates of combustion, but the more rapid it is, the greater is the efficiency of the tubes as heating surface, owing to the greater amount of heat they are able to absorb. In this respect the express boiler has the advantage, compared with the usual forms of large tube boiler, that its tubes are comparatively short and direct, and more nearly vertical; also, each tube discharges into the steam drum independently of the

rest, and the small diameter of the tubes causes a more rapid generation of steam. The cause of circulation has been the subject of much controversy, and though opinions still differ on the theoretical side of the question, all are agreed as to the steps that should be taken in practice to secure a good circulation. In reference to the economy of the express boiler, widely varying results are brought about by apparently trivial, and in most cases, preventable causes. The first condition of economy is perfect combustion. The express boiler has a large grate, which requires a thin but even fire; if too thick in places the air cannot penetrate and the coal clinkers; if too thin, the air enters the fire-box insufficiently heated.

Most destroyers have four boilers, but some have only three, while in others there are eight. In all cases there are two stokeholds. Coal is stored in bunkers along the sides of the boiler space, and in an athwartship bunker forward. The forced draught is supplied by fans, generally having vertical shafts, and situated close under the deck. In this case they are single-breasted, being joined directly to the base of their cowls, and are driven by single-cylinder horizontal engines, the full speed of which is about 400 revolutions per minute. Double stokeholds, that is, with fires back and front, have two fans, one on each side of the ship; single stokeholds have one central fan. The air usually enters the ash-pits direct, through thin doors which swing inwards and close when there is no excess of pressure on the stokehold side. An excellent system adopted in the Yarrow boiler is to take in air through similar doors high up in an outer casing; there it is heated and helps to keep the casing cool, the hot air passing on to the fire. This arrangement provides an additional safeguard against flames being forced into the stokehold by an occurrence of back pressure.

Owing to the small quantity of water contained in these boilers and the consequent rapid evaporation, the feed system assumes unusual importance. Some form of automatic feed is generally considered almost indispensable, though one foreign government prefers to trust to the human element rather than to any mechanism. Nearly every express boiler has its own form of automatic feed apparatus, but most of them consist of a valve worked by a float either within the steam drum or in a chamber connected with it. Such an apparatus is always capable of adjustment to suit different rates of combustion, or for operating the valve by hand; in the Thornycroft regulator the fulcrum of the float is raised or lowered by a screw outside the steam drum; in the Blechynden regulator

the valve seat slides within its casing and can be adjusted by an external screw, so that the valve can be opened either automatically by the float moving the valve spindle, or at will by moving the valve seat. Both of these forms have been found to work satisfactorily in practice. Messrs. Yarrow have tried a form of automatic feed in which the steam-pipe to the feed-pump is led from a conical pan placed in the steam-drum with its upper edge at the normal water-level, the object of this being to enclose a body of water unaffected by the disturbance of the surrounding water. So long as the top of the pan is uncovered, steam is supplied to the pump, but when the pan is covered with water the pump is choked with the water that comes over in the pipe. Adjustment is effected by raising or lowering the pan, there being a joint in the pipe connecting with it. This arrangement necessitates a separate pump for each boiler. An installation of Normand boilers has been fitted, in which the steam-drums are connected by pipes below the water-level. This has the effect of steadying the water-level in each boiler, and it is only necessary to watch one boiler; but it adds to the weight and complication of pipes, as valves have to be fitted to enable any boiler to be shut off.

Opinions differ on the subject of the best place to admit the feed. At first it was usually admitted in the lower drums, but the practice soon became general of admitting it into the steam drum, chiefly with the object of assisting circulation by allowing it to flow downwards inside the boiler, and also to distribute it more evenly. Recent experiments, however, with the Blechynden boilers of H.M.S. "Pactolus" have shown an increased efficiency when the feed is admitted at the lower drums. Mr. Yarrow has described an interesting series of experiments in connection with feed-admission. He has found that by partitioning off the outer rows of tubes and admitting the feed to these first, the same number of tubes will absorb a greater amount of heat from the fire than if the feed is permitted to follow its natural course in the boiler. This result has verified the theory that the hottest gases should meet the hottest tubes, and *vice versa*, and is another illustration of the efficiency of the feed-heater placed in the uptake, often called the economizer. This efficiency is due to the fact that the difference in temperature between the cold-feed and the uptake gases is sufficient to cause a useful exchange of heat, whereas if the same gases acted on a surface containing hotter water the exchange of heat would not be worth considering. It seems rather wasteful, however, to use part of the boiler as a feed-heater, since a feed-heater requires no provision for circulation

and can consist merely of coils of small pipes. There is little doubt that the boiler of the future will receive its water from a heater at the boiling-point due to its pressure, as it has been proved that a marked economy can be obtained by heating the feed to boiling-point, even by live steam from the same boiler.

The system of feed-pipes and pumps is in duplicate, being termed main and auxiliary. The main feed-pumps are preferably placed in the engine-room, where they are under better control, and are free from the ruinous effects of coal-dust, but the auxiliary feed-pumps are placed in the stokehold to be available in case of emergency, such as the failure of the automatic feed. Filters are fitted either on the suction or discharge side of the feed-pumps, and consist of layers of brass grids covered with the filtering composition, which is easily replaced when clogged, a by-pass being fitted for this purpose. Suction-filters are the lightest, since they are not subject to pressure, but the action of the discharge-filters is more certain. The latter are fitted with relief-valves to prevent excessive pressure in the pipes owing to the filters getting clogged. A reserve fresh-water tank is fitted, generally built into the ship's frames, for making up the feed. An evaporator and distiller is also fitted for producing fresh water both for drinking purposes and for the boilers. No oil has been used in the cylinders of these engines, and no trouble has been caused by the want of it, in spite of their high piston-speed. However, enough oil always finds its way into the steam by means of the rods to render filters a necessity when express boilers are used.

Steam-pipes are now of solid-drawn steel, when of larger diameter than 1½ inch, and below this size solid-drawn copper pipes are allowed; the earlier destroyers had solid-drawn copper pipes considerably above this size. Flanges are screwed on for small sizes and riveted for large sizes. Bends and tees are of gun-metal or cast steel; the latter is rapidly growing in favour, as reliable castings can now be obtained much thinner than was formerly practicable, and at a reduced cost. There are usually two ranges of main steam-pipes, on opposite sides of the ship, one from the forward, the other from the aft group of boilers, having stop-valves and a cross-connection in the engine-room, as well as the boiler stop-valves and regulator-valves on the engines. They slope gradually towards the engines, and are drained by steam-traps discharging into the feed-tank. The auxiliary engines are supplied with steam by a separate range of piping having separate stop-valves on the boilers, and they can exhaust into the condenser

or through a pipe at the side of the funnel. A silent blow-off is fitted from the main steam-pipe to the condenser. Gauge-glasses continue to be of glass, though they are an endless source of nuisance and sometimes danger at high pressures. Mica has been tried, but it soon discolours; it may be said that a trustworthy means of rendering the water-level visible and resisting high steam-pressures has yet to be found. Water-nozzles are fitted in the furnace-fronts for drenching the fires. The steam-pressures employed in these vessels range between 180 lbs. and 250 lbs. per square inch. The latter is not so high as the pressure employed in the Belleville boilers of H.M. cruisers and battleships, in which the boiler-pressure is 300 lbs. per square inch, but in their case it is reduced to 250 lbs. per square inch at the engines, while no reducing-valves are used in destroyers.

Engines.—The type of engine adopted in these vessels has been either the three-crank or the four-crank inverted triple expansion engine. In choosing between the two types a consideration secondary only to that of weight and space is that of balancing. Since the magnitude of the inertia-forces in an ordinary steam engine varies with the mass, the stroke, and the square of the number of revolutions per minute, it will be seen that of two engines having the same piston speed and the same weight of moving parts, the one with the shorter stroke and higher rate of revolution causes most vibration, and in a destroyer the highest piston speed and the highest rate of revolution are combined. The effect of these forces is greatly magnified by the light scantlings of the hull, the stiffness of which cannot be relied upon to the extent possible in larger ships. The three-crank engine was more common in the 27-knot boats, but in the 30-knot boats the four-crank engine has in many cases taken its place, and has practically become the standard type for high-speed engines. The three-crank engine, however, has much in its favour; its twisting moment is more uniform, it takes up less fore and aft space, and has fewer working parts, with a correspondingly reduced risk of breakdown. Although three cranks at 120° would constitute a statical balance about the centre of the shaft if the pistons were of equal weight, dynamical stresses are set up by the successive acceleration and retardation of each set of moving parts, and though the sum of the forces set up in a given direction is nearly equal throughout the stroke to that of those set up in the opposite direction, they do not act in the same plane, and therefore constitute a couple, varying with the distance between the planes in which the resultant opposing forces act. This couple tends to cause the ends

of the engine to move in opposite directions, this tendency being greatest in the vertical plane, as the forces due to the vertically reciprocating parts are then added to the centrifugal force of the revolving weights.

Vibration in the three-crank engine has, so far, been met by balance-weights placed on the crank-webs. By this means all forces due to the revolving parts can be eliminated, but it is obvious that if the revolving balance-weights be increased till they balance the vertical forces of the reciprocating parts, horizontal forces of the same amount are introduced, and thus the effect is merely to change the vertical forces to horizontal. Indirect though this method may seem, it has met with considerable success in reducing vibration, as trials with and without balance weights have proved, and seems to show that a vessel of this type is stiffer in a horizontal than in a vertical direction, at any rate at the bed-plate, where the forces are applied. It is sometimes considered sufficient to balance the revolving parts, while a good compromise seems to be found in proportioning the forces to the stiffness of the ship in the direction in which they act, thereby reducing the maximum force exerted. The increasing preference shown to the four-crank engine is largely due to a desire to obtain a self-balanced engine, though it has the important advantage of keeping the diameter of the cylinders, and consequently the breadth of the engine, more uniform, two low-pressure cylinders, very little larger than the intermediate, being substituted for the single larger cylinder. Obviously the length of the engine is considerably increased, but it is in breadth of engine-room space rather than in length that the designer is cramped. Returning to the question of balance, though the four-crank engine lends itself to obtaining an almost perfect balance with a correct disposition of cylinders and crank angles, until quite recently engineers have been content to place the cylinders in their natural sequence, with the high-pressure crank directly opposite to the intermediate-pressure crank, and the two low-pressure cranks opposite each other, the high-pressure and intermediate-pressure cranks making an angle of 90° with the low-pressure cranks. In this case there are two distinct unbalanced couples set up, the one reaching its maximum when the other is at zero. The magnitude of the couples, however, is in no case as great as the couple set up by a three-crank engine of the same size, unless No. 1 crank be placed opposite No. 4 crank, which is the worst sequence possible. The opposite cranks, therefore, should be brought as close together as the cylinders will permit.

The Thornycroft engine is the outcome of an effort to get rid of even this limitation, and to reduce the couple to a negligible quantity. In this engine the two adjacent crank-pins are joined by a single web without a middle bearing, the cylinders being placed radially at a slight angle on each side of the vertical. The adjacent cranks make with each other an angle of 180°, less the angle between the centre lines of their cylinders, so that both cranks reach the end of their strokes simultaneously. This arrangement has not only attained its object in reducing vibration to a minimum, but reduces the pressure on the main bearings. The pressures on the crank-pins to a great extent counteract one another, and the main bearings, instead of receiving the full load due to the steam pressure, receive little more than that due to the couple depending on the fore and aft distances between the crank-pin centres. In other words, supposing the fore and aft distance between the main bearing centres to be double the distance between the crank-pin centres, the pressure on the main bearings would not be much more than half that on the crank-pins. It is not exactly half, owing to the inclination of the cylinders to one another. Further, the load on the main bearings being reduced, the load on the columns is correspondingly reduced, the fitting bolts connecting the adjacent cylinders being in shear. There is a slight tendency to horizontal vibration in this engine, owing to the sideways movement of the parts, but the effect is scarcely noticeable. Mr. Thornycroft has pointed out and illustrated by the simple means of two pieces of twisted wire that a pair of cranks without a middle bearing in transmitting a twist has not the tendency to displace the centre of the shaft that a single crank has, since any distortion in one crank-pin and any deflection in one crank-web is neutralized by a similar condition in the opposite crank. He attributes many failures of crank-shafts to their being brought out of line by the distortion of the cranks, but, considering the severe bending stresses tending to throw a crank-shaft out of line, this slight tendency seems almost trivial, especially as it cannot occur unless the cranks be not stiff enough to transmit the twist without distortion. The claim to reduced initial friction with this type of engine compared with the three-crank engine seems amply justified by progressive trials with the two types of engines, the initial friction in each case being obtained by producing the curve of indicated thrust to zero speed. This type of engine has the slight disadvantage of having very short eccentric rods for two of the valves, the other two having a good length of rod; this is caused by the link motions

being at different inclinations,[1] but suspended from a common weigh-shaft at the side of the engine. It is also possible that the cylinders may after a time be found to have worn slightly oval owing to their inclination from the vertical. The ordinary vertical four-crank engine has been found to run fairly steadily when the opposite cranks have been brought as close together as possible, but where they have been separated by a piston-valve balance-weights have as a rule been found necessary.

The combined piston-valve adopted by Messrs. Belliss in H.M.S. "Swordfish" and "Spitfire" must of necessity be placed between the two cylinders with which it is connected. It amounts to placing two valves one above the other on a common spindle and driven by one set of link motion, the valve-chest being common to both cylinders. If the valve-settings of both cylinders are the same, then the cranks must be opposite, or at any rate nearly so, if different valve-settings are required. This type of valve reduces the fore and aft length of the engine considerably without increasing its breadth, and obviates the cost of two sets of link motion; it has, however, the drawback of presenting a more complicated casting, which is not desirable with such thin metal, and the setting of one valve cannot be altered independently of the other; it also necessitates the centres of the opposite cranks being a greater distance apart. To reap the full benefit of the four-crank engine, the crank angles should be arranged so that there is no resultant couple and very little resultant force. It is of course desirable that there should be no resultant force, but this is not at present practicable owing to the disturbance caused by the obliquity of the connecting-rod.

With the exception of those built by Messrs. Laird, which have their engines in the middle of the ship, as being the position where the hull is least susceptible to vibration, all the British destroyers have their engines aft of the boiler space, placed side by side, with no middle bulkhead. The favourite arrangement in America seems to be to place one engine-room forward of the other and separated from it by a water-tight bulkhead, the engine space occupying the middle of the ship, and the boilers being in two groups, one forward and one aft. This arrangement has the advantage of completely isolating each set of engines and boilers, and also that the coal-bunkers, which, contrary to English practice in these vessels, are situated on either side of the engine space, may afford a slight protection to the engines,

[1] For the exact difference, see Thornycroft and Barnaby on "Torpedo-boat Destroyers," Minutes of Proceedings Inst. C.E., vol. cxxii. p. 51.

but, on the other hand, the engines occupy a much larger portion of the ship than if placed side by side.

Returning to English practice, the condensers are placed in the wings with the ordinary type of engine, and are made long in proportion to their diameter, in order to reduce weight and also to give more room for a gangway between the engines. The length of the condenser is limited by the necessity of having sufficient clear space at one end for drawing tubes. In the case of the Thornycroft engine, which is broader and shorter than the ordinary engine, the condenser is placed aft of the engines. The centre lines of the shafts have always to be slightly inclined from the engine-room downwards, to immerse the propellers, and as a rule they are slightly inclined outwards, to bring the engines as close together as possible. Some of the earlier destroyers were arranged to secure a broad gangway between the two engines, there being no room to pass between condensers and engines. This is the best arrangement for vessels of very narrow beam, but as the screws (with the exception of those of H.M.S. "Conflict") revolve outwards, a good view of the engines is not obtainable from a centre gangway, as the piston-rods and connecting-rod top ends are to a great extent hidden by the guides. As the distance between the engines is increased, the centres of their shafts have to be raised, owing to the rise in the ship's bilge; consequently the general practice is to secure a free gangway at the outside of each engine, where the only unavoidable obstructions are the exhaust pipes to the condensers, and to bring the engines as close together as the space necessary for steam pipes will admit. In most of the 27-knot boats the air-pump is placed forward of the engines in a continuation of the crank-pit and is driven by a connecting-rod from a small crank-shaft, which forms a continuation of the main crank-shaft. Height is saved by adopting the trunk form of bucket, the connecting-rod eye working on a pin secured at the lower end of the trunk. In this arrangement the air pump occupies no room that might be otherwise useful, as the floor plates can be carried above it, a lid being fitted for inspection and oiling. As, however, the stroke of the pump is limited to 4 inches, the diameter, and consequently the clearance, is excessive. It has also proved troublesome on account of the bearings becoming heated, which is probably due to some extent to its being out of sight. For these reasons it has been abandoned in the 30-knot boats, in favour of the usual lever-driven pump, driven from the aft low-pressure cylinder and placed on the outside of the engines; it does not then obstruct the gangway as there is room to pass in

the space left for drawing the condenser tubes. In a fore and aft direction, space is most required at the forward end, as in nearly every case the hand gear and pressure gauges are brought to this end and room has to be found for two main feed pumps, two circulating pumps, an evaporator, distiller and engine, a fire- and bilge-pump, in some cases feed-heaters and separators, and an air-compressor for the torpedoes. The steering engine is always placed on the aft engine-room bulkhead, between the thrust blocks, and the electric-light engine is placed in the next compartment abaft the engine-room, which is used as a galley and a store.

The main-engine cylinders are not jacketed, the usual thickness for high-pressure cylinders being $\frac{3}{4}$ inch. They are independent castings (with the exception of Messrs. Belliss's arrangement, already mentioned) connected by brackets top and bottom; each cylinder has its own valve chest cast with it; steam-joint connections, such as are found in the merchant service, are not permitted. Since the expansion of the line of cylinders is a condition to be reckoned with, it is usual to fit the liners between these brackets when the cylinders are hot. The framing has to yield to the expansion in any case where the cylinders are bolted together, but this method ensures the cylinders being in line under working conditions. Piston valves are always fitted for the high-pressure and intermediate-pressure cylinders, and as a rule also for the low-pressure cylinder. The high steam-pressures employed render these a necessity for the high-pressure and intermediate-pressure cylinders, while even for the low-pressure cylinder a piston-valve and chest is lighter than a flat valve and chest, though it takes up more room. It has greater freedom in running at high speeds, and if carefully fitted, the steam has scarcely time to leak past it. Piston valves are of cast iron, though aluminium has been tried, and have no packing rings, but often have a number of small grooves on the working face, in which the condensed steam collects. These grooves have been found to assist in keeping the valve tight and in lubricating the working faces. All flat surfaces, such as steam ports, are stayed with fine-thread steel stays screwed into bosses in the casting, and caulked at their projecting ends. Steam is admitted between the steam ports to the annular space round the valve, exhausting at the outer edges. The valve-chest glands are then subject to steam at a lower pressure than with the reverse arrangement. When a flat slide-valve is used, a compact arrangement is to exhaust the steam through the back of the valve chest, the usual relief ring being employed to keep the passage tight. The crank-shafts are of mild steel and are forged

in one piece, the shaft and crank pins being hollow. The bore is usually half the diameter or slightly more. The crank-webs have their corners bevelled or rounded to save weight, and balance-weights, when required, are driven on to mortices on the crank-webs and secured by strong studs. In the coupling between the crank-shaft and the thrust-shaft, "drivers" are usually employed instead of the ordinary fitted bolts, to prevent the possibility of any thrust coming on the crank-shaft. They are held by nuts in taper holes in the thrust-shaft coupling-flange, and fit easily in the holes of the crank-shaft coupling-flange, the two flanges being about ¼ inch apart. The coupling between the thrust- and tail-shafts consists of a swelling in the thrust-shaft, into which the end of the tail-shaft fits, and is secured by one or more cotters. This is the simplest form of coupling where the tail-shaft has to be drawn outboard and access is limited. The cotters transmit both the twist and the thrust, whereas in the ordinary form of loose coupling special provision has to be made for transmitting the thrust. The tail-shaft is carried at each end by cast-steel tubes lined with white metal, the forward of which is driven into a tube built into the ship and the after into what is generally known as the A-bracket, both of these parts being bored out in position. The tail-shaft is open to the sea for the greater part of its length, but though exposed to rust, there are no brass liners to set up galvanic action. Zinc rings are fitted on the shaft at the forward end of the propeller to minimize galvanic action caused by the latter. The aft end of the tail-shaft is completely covered by the propeller nut, which in turn is covered by a light brass cone which follows the outline of the propeller boss and fills up the vacuum which would otherwise be caused there. The propellers are three-bladed, the blades being in one casting with the boss. They are of high strength bronze, such as manganese- or aluminium-bronze, or Stone's metal. With the exception already mentioned they revolve outwards, as the outward current tends to throw clear any floating *débris* or ropes, instead of drawing them inwards. In large naval vessels, which have their propellers more deeply immersed, this consideration is not so important, and the latest cruisers have propellers revolving inwards to bring the open fronts of the two engines towards the centre of the ship for convenience in handling. In a series of experiments recently described before the Institution of Naval Architects,[1] Mr. R. E. Froude has found that there is practically no difference in efficiency

[1] Transactions of the Institution of Naval Architects, vol. xl. p. 61.

depending on the direction of revolution. Experiments have proved that a high-speed propeller of small diameter, large blade area and coarse pitch is the most efficient, as the reduction of surface friction secured by the lower average velocity compensates for the coarser angle of blade. The slips obtained on successful trials in these vessels range between 15 per cent. and 8 per cent., and as a rule the best results are obtained with the higher slips. At a certain point, however, increase of slip ceases to be attended by increased thrust. This is probably chiefly due to the phenomenon now known as "cavitation," which was met with in a marked degree in the first propellers of the "Daring," as described by Mr. Thornycroft in the Paper already mentioned.

The thrust blocks are of cast-iron, and are of the solid type, bushed with white metal and water jacketed; they are generally carried on cast-steel bearers bolted to longitudinal girders of angle or channel section. These girders are sometimes of cast-, but more commonly of rolled-steel, and run the whole length of the engines from the thrust blocks to the air pump, if the latter is of the crank type. The engine bed-plates are separate castings, usually of cast-steel, but sometimes of bronze, of I section, bolted at their ends to these guides, which are themselves carried by deeper longitudinals built into the hull of the ship, the space between them forming the crank-pits. They are stiffened by frames on each side and are connected by frames directly under, and bolted to, the bed-plates. The guides are of cast-iron of the slipper type with a water-jacket behind the go-ahead face. They are bolted at their upper ends to a flange on the cylinder bottom, and at their lower ends to horizontal stays between the columns. The columns are usually of forged steel turned bright, and are stayed by horizontal stays passing through swellings in the columns, near their centres. Diagonal stays are generally also fitted. Exceptions to this type of framing are H.M.S. "Salmon" and "Snapper," in which the back columns are bronze, of bulb section and somewhat bow-shaped, the cast-iron guides being bolted to them by continuous vertical flanges. This section of column is stiffer, weight for weight, than the round column, but is much more expensive, and the same stiffness can be secured with round columns by the use of diagonal stays. The piston-rods and connecting-rods are drilled hollow to about half their external diameter, and the crossheads are in one piece with the piston-rods, the gudgeon pins being shrunk into the connecting-rod forks. The gudgeon pins are hollow and of specially hard steel. The engines are stayed to the bulkheads and to the ship's sides by

stays consisting of tubes with palms welded on each end, running from gussets close under the deck, to lugs cast on the cylinders. The two sets of engines are similarly stayed to each other. Though the slot- or locomotive-link has been adopted in some of these vessels, the usual double-bar link is preferred, as it admits of adjustment in every wearing part, gives a truer motion, and is lighter for the same strength. The eccentric-straps are of gun-metal or phosphor-bronze lined with white metal. They are ribbed between the bolts, usually by T or bulb-shaped ribs. Joy's assistant cylinder has been fitted in a few vessels of this class, and has reduced the wear on the valve-gear considerably. This device consists of a piston connected to the valve spindle, working in a cylinder, to each end of which it admits steam in turn. By regulating the amount of steam admitted, it can be made to do the work of moving the valve in each direction, the valve gear merely controlling the length of travel. The all-round reversing-gear still obtains, on account of its simplicity and compactness; the earliest destroyers were reversed by hand, but steam reversing gear was very soon introduced. The arrangements for oiling demand considerable attention in these rapidly moving engines. Centrifugal lubricators are fitted to the crank-pins and often to the eccentrics; in addition, oil is led by the usual wick siphons from oil-boxes placed at about the level of the cylinder bottoms. These boxes also supply oil for the guides, crosshead brasses and link motion. The main-bearing oil-boxes are situated lower down. Separate oil-boxes are provided for the glands, as only mineral oil must be used. These engines, having hollow shafts, are well adapted for a system of forced lubrication, such as that used by Messrs. Belliss in their type of enclosed electric-light engine, in which the oil is forced by a pump through pipes passing through the shaft and crank webs to the crank pins, and thence to the crossheads and guide slippers. Water is led from the circulating pumps by pipes laid along each side of the engines, for playing on the eccentrics, bottom ends and main bearings, and for circulation through the water jackets in the guides and thrust blocks. The condensers are built of sheet-brass plates riveted together, and stiffened by angle rings. The tubes are of solid-drawn brass, $\frac{5}{8}$ inch in diameter and about 18 Lancashire Gauge in thickness; they are packed with the ordinary screwed ferrule and tape packing. Owing to their great length they require a central supporting plate. The circulating water flows through all the tubes together, making only one passage through the condenser. It is fed by scoops in the skin of the ship at the curve of the

bilges. When the ship is at full speed the pump has little or no work to do but to keep pace with the water, as the speed of the ship is generally sufficient to force the water through the condenser. This is not, however, an advantage; in fact, it is certain that the scoop causes a resistance to the speed of the ship, out of all proportion to the steam saved in the centrifugal pump, and the failure of some of these vessels to attain their contract speed at first has been traced to the form of scoop employed; some form of scoop is, however, a necessity, as the pump cannot suck in the water without one, and a scoop that is able to get the water into the suction-pipe at all generally gives it sufficient velocity to carry it through the condenser. The ideal scoop should give the water just sufficient velocity to carry it to the circulating pump. The circulating pumps, of which there is one for each condenser, are of the centrifugal type, and are arranged so that the flow of water is as continuous as possible; they are driven by single-cylinder engines of about 3½ inches stroke, the full speed of which is about 300 revolutions per minute. A small air-pump is driven off the crank-shaft of each of these engines, for clearing the condenser of water and to maintain the vacuum when the main engines are standing. It delivers to the feed-tank and can also draw from the reserve tank to make up the feed. The fire- and bilge-pump is generally of the duplex type, and sucks from boiler-room and engine-room bilges or from the sea, and discharges overboard, or to a hose-connection on deck when it is used as a fire-pump. As a bilge-pump it is assisted, when necessary, by bilge-ejectors placed in the engine-room, in the stokeholds, and in the compartments forward and aft of the machinery space. These are placed on the skin of the ship close to the deck and merely consist of a nozzle emitting a jet of steam, which draws up the water from the bilges and discharges it overboard. They are useful in the event of the bilge-pump getting choked, while they are not liable to get out of order, as they have no valves and the steam has a scouring effect.

OBITUARY.

JOHN ORME ANDREWS was born at Kennington on the 8th June, 1832. He was articled at the age of sixteen to Mr. T. J. Ditchburn, shipbuilder, of Millwall, and was subsequently transferred to the works of Messrs. Bramah and Robinson, Mechanical Engineers, of Pimlico. In 1852 he was for some time employed in the engineering works of Messrs. Napier and Son, of Lambeth, and in 1855 he was engaged under the late Mr. John Gardner in preparing designs for bridges on the Staines and Wokingham Railway, including the working drawings for the bridge over the River Thames at Staines.

In 1856 Mr. Andrews was appointed by the Admiralty Second Assistant Engineer on the works of the Portland Breakwater under Mr. (subsequently Sir John) Coode, Past-President; in 1862 he was promoted to First Assistant Engineer, and in 1867 to Acting Engineer on Sir John Coode relinquishing the charge of the works. Mr. Andrews remained at Portland until 1880, and during his long period of employment there he carried out extensive works for the completion and maintenance of the breakwater; piers, harbour and other works, including the supervision of the construction of the railway connecting the breakwater coaling jetty and the terminal station of the Great Western branch line at Castletown.

He also had charge of the Coast-guard stations extending from Seaton, on the Devon Coast, to Southampton Water, including the building of a new station at Poole Harbour, and additions to other stations, as well as their general maintenance. On Sir John Coode retiring from the post of Engineer-in-Chief at Portland in 1867, Mr. Andrews had sole charge under the Director of Admiralty Works.

In 1880 Mr. Andrews was appointed—in succession to his brother Charles—Superintending Civil Engineer at Haulbowline. There he had sole charge of the completion of the basin and dry dock on Haulbowline Island, a work mainly executed on reclaimed mud banks lying between Haulbowline and Spike Islands. Considerable engineering difficulties were met with in this work, particularly in the foundations for the deep water basin and dry dock; all these, however, were successfully overcome, and the

work completed in the spring of 1888, when Mr. Andrews retired from the public service, receiving a pension from the Admiralty.

Mr. Andrews was also professionally engaged on engineering questions by many county authorities, as he possessed a thorough practical knowledge of dock and river engineering. After a professional career of nearly forty years in continuous employment, during which he earned the affection and respect of all he came in contact with, he retired with his family to Ealing, where he died on the 16th February, 1900, from an attack of pneumonia, leaving a widow and six daughters. In private life he was a most kind and genial man, and in addition to his professional abilities possessed considerable skill in the fine arts as well as in music.

Mr. Andrews was elected an Associate of the Institution on the 1st December, 1863, and was transferred to the class of Members on the 8th May, 1877.

GEORGE AUGUSTUS D'AUVERGNE ANLEY, born on the 16th November, 1833, served the usual period of pupilage under Mr. George Sibley (late Chief Engineer of the East Indian Railway Company). In 1857 he was appointed an Assistant Engineer on the East Indian Railway Company, and served in the Beerbhoom District until 1859, when he was transferred to the Rajmahal District, and placed in charge of the heavy rock-cutting and the construction of the railway between Behawa Station and Rajmahal Junction. On the completion of that work in January, 1861, he was allowed, on the application of the Government of India, to leave the service of the East Indian Railway Company, and was appointed an Executive Engineer, 4th-grade, in the Public Works Department. He was posted to the Pooree Division in Orissa, and placed in charge of the roads, buildings and embankments in that district. In November, 1862, he was transferred to the Balasore Division, and placed in charge of the remodelling and construction works of the Orissa Trunk Road, of the public buildings and embankments in that division, and of the improvement of the navigation of the river Burrabullong. In March, 1865, on the application of the Municipality of Calcutta to the Government of India for an engineer to officiate for Mr. William Clark, Municipal Engineer, he was transferred temporarily to the service of that Municipality, and was in charge of the extensive drainage works then being carried on, and of all other

works falling within the duties of a Municipal Engineer, until December, 1868, when Mr. Clark returned to India. Mr. Anley then reverted to his appointment under the Government of India, and was placed in charge of the works on the road (124 miles) extending from the Ganges River to the foot of the Darjeeling Hills, on which several large bridges were erected, and of all roads and buildings in the Purneah District. In September, 1875, Mr. Anley was appointed to officiate as a Superintending Engineer, first of the Presidency Circle and afterwards of the North-West Circle. In April, 1876, he became Assistant to the Chief Engineer, and Assistant Secretary to the Government of Bengal in the Public Works Department, and held those posts until March, 1880, again acting for a short period during that time as Superintending Engineer of the Presidency and North-West Circles. In March, 1880, he was appointed to officiate as Superintending Engineer, 3rd-Class, and placed in charge of the Eastern Circle of Bengal. In March, 1882, he was permanently promoted to the rank of Superintending Engineer, 3rd-class, and in July, 1884, to the rank of Superintending Engineer, 2nd-Class, in which rank he served till his retirement from the service in 1888. He designed the large and handsome Eden Hospital for Women in Calcutta, which was erected under his supervision. Mr. Anley was elected a Member of the Bedford Town Council in 1899, and died in that town on the 16th February, 1900.

He was elected a Member of this Institution on the 19th May, 1885.

HENRY BANCROFT, born on the 17th June, 1834, was the eldest son of the late Mr. James Bancroft, of Broughton Old Hall, Manchester, who was for many years Vice-Chairman of the London and North Western Railway Company. He commenced his professional career in the City Surveyor's Office, Manchester, afterwards entering the office of the late Mr. Bateman, Past-President, by whom he was entrusted with much important work, both as an assistant and in after years when practising on his own account. On leaving Mr. Bateman he was appointed Resident Engineer on the Fylde Waterworks and the Blackpool and Lytham Railway, under Mr. T. B. Foster, and on the completion of those works, in the year 1864, he commenced business on his own account.

During his thirty-six years of private practice Mr. Bancroft designed and carried out many important works, notably the sewer-

age and sewage disposal of the Borough of Colne, in Lancashire, and the waterworks for Northwich.

Mr. Bancroft married the eldest daughter of the late Mr. Robert Neill, of Manchester, who survives him. He died at Southport on the 15th May, 1900, leaving four sons, the eldest of whom was a partner with him for the last six years.

Mr. Bancroft was elected an Associate of the Institution on the 4th May, 1875, was subsequently placed in the class of Associate Members, and was transferred to the class of Members on the 3rd December, 1878.

HORATIO BROTHERS died at his residence, The Elms, Putney Hill, on the 19th December, 1899, after a short attack of influenza. Born on the 30th November, 1822, he was a younger son of Lieutenant Francis Brothers, R.N. In 1844 he became an assistant to his brother, Mr. O. Brothers, then Engineer to the Blackburn Gasworks, and after obtaining further experience on various works of a similar kind in Lancashire, he was appointed in 1852 Engineer to the Salford Corporation Gasworks. That post he held until 1859, when he came to London to take up the office of Engineer to the Equitable Gas Light Company, which under his management became one of the most flourishing undertakings of the metropolis. On the amalgamation in 1871 of the Equitable with the Gas Light and Coke Company, Mr. Brothers remained, until his retirement in 1879, as Engineer in the service of the latter Company.

In addition to the appointments above mentioned, Mr. Brothers carried on, previous to his retirement, a large private practice as a consulting engineer. The Gasworks at Croydon, Bromley, Worthing, and other places, were erected under his superintendence, and he was frequently retained to give evidence before Parliamentary Committees. He was Chairman of the Bahia Gas Company up to the close of its concession in 1897, and at the time of his death was Chairman of the Gas Meter Company and of the Ceará Gas Company.

Mr. Brothers was elected a Member of the Institution on the 1st March, 1870.

WILLIAM DUFF BRUCE, who died on the 24th April, 1900, was a son of Mr. George Williamson Bruce. He was born on the 10th April, 1839, at Brooklawn, near Mowhill, County Leitrim, an

estate which his father, who was a member of a Banffshire family, had temporarily taken. At the age of nine he was sent to St. Andrews, where he remained until 1855, when he was recalled to Ireland, and apprenticed to Messrs. Thomas Grendon & Co., of Drogheda, a firm largely engaged at that time in the construction of locomotive and marine engines and in general millwright work. Having spent four years in the workshops, Mr. Bruce subsequently followed up his studies at St. Andrews with a course of engineering, with a view of competing for an appointment in the Indian Public Works Department, examinations for which had been organized by Lord Stanley of Alderley, then Secretary of State for India. Taking second place in the examination of 1860, Mr. Bruce was appointed to the Public Works establishment in India. He arrived in that country at the end of that year, and was sent to Roorkee College in order to further study engineering and to acquire a knowledge of native languages. Six months later he was posted as an Assistant Engineer to the Cawnpore Division, and was placed in charge of the Futtegarh Sub-Division, where he built the church erected in memory of the residents who had been killed during the mutiny. From there Mr. Bruce was transferred to Oudh as Assistant to the Chief Engineer and Secretary to the Chief Commissioner in the Public Works Department in Lucknow. He held that post for two years, and was then promoted to the grade of Executive Engineer and appointed to the Lucknow Division, where roads and barracks in the new military cantonment were carried out under his direction. He also designed and built the bridge across the Goomtee, three spans of 80 feet each, in brickwork.

In 1867 Mr. Bruce was transferred from the Lucknow Division to Calcutta, where he was appointed Executive Officer in charge of the Second Calcutta Division, in which was included all the new public buildings then under construction, viz., the Telegraph Office, the High Court, and the Indian Museum. After spending three years in that position he was posted to the Hooghly River Division, which included the charge of new wharves and jetties, and the carrying out of improvements for facilitating the landing and shipping of goods at Calcutta. In 1870 the whole of these works were placed under the Port Trustees, a body formed on the same lines as the Mersey Dock Trust, and styled the Commissioners for making Improvements in the Port of Calcutta. Of this body Mr. Bruce was appointed Vice-Chairman and Chief Engineer, in which capacity he designed and carried out all works for the improvement of the Port. In 1873 the river works, *i.e.*, the works on

the Hooghly between Calcutta and the sea, were transferred by Government to the charge of the Calcutta Port Commissioners, and Mr. Duff Bruce had then charge of the lighthouses, lightships, and the survey of the river, and of all works which were carried out from that time until his retirement in 1889.

In 1882, at the instance of Government, the question of providing docks at Calcutta was brought forward, and after much investigation sanction was given to a scheme prepared by Mr. Bruce. The docks, commenced in 1884, were fully described by him in a Paper read at the Institution in 1895,[1] for which he was awarded a Telford medal and premium. The cost of constructing the docks and the works connected therewith was about £2,250,000. Mr. Bruce continued in charge of the works in India until 1887, when he returned to London in the capacity of Consulting Engineer to the Port Commissioners. In 1889 he retired from the service, but retained the appointment of Consulting Engineer to the Port Commissioners. The records of the Commissioners' Proceedings show how highly Mr. Bruce's services were appreciated, and with what success he so long filled the responsible position of Chief Executive Officer of the Port.

In 1887 Mr. Bruce commenced business at 17 Victoria Street, Westminster, as a Consulting Engineer. He was appointed Consulting Engineer to the Delhi Umballa Kalka Railway, and in 1890 to the Assam-Bengal Railway Company, concessions for both of which he obtained from the Secretary of State. He was also connected with the establishment of ironworks in India, which, after many years of difficulties, are now being profitably carried on, his untiring zeal having largely contributed to the success attained in this direction.

For some years Mr. Bruce was a Director of the Rio Tinto Company, and at the time of his death filled the position of Deputy Chairman. His firm also acted as Consulting Engineers for the Company. Mr. Bruce, with his co-Directors, paid yearly visits to the mines at Rio Tinto, and many mementoes exist to show the interest he took in those visits. Many important changes were carried out at his suggestion, and his technical skill was of great service to the Company.

During the years Mr. Bruce practised at Westminster, many important works were designed by him in connection with the railways and other undertakings for which he acted as engineer. In all these he displayed skill and great capacity for work. He was a sol[illegible] WIL[illegible] was 10th April, [illegible]

[1] Minutes of Proceedings Inst. C.E., vol. cxxi. p. [illegible]

drew around him a devoted staff, by whom his kindness and consideration will be remembered with gratitude. Those in his office who were privileged to come close to him had learnt not only to respect but to highly regard him, and feel that they have lost by his death a good master and a kind friend.

Mr. Bruce was elected a Member of the Institution on the 7th March, 1876.

PETER SCHUYLER BRUFF, born on the 23rd July, 1812, obtained his early engineering experience under Mr. Joseph Locke, Past-President. The knowledge of railway construction thus gained he subsequently turned to account in the Eastern Counties, where his great work was the establishment of railway communication between Colchester and Norwich. The old Eastern Counties Railway had been constructed from Shoreditch as far as Romford, in 1835; in the following year it was carried to Brentwood, and in 1843, after considerable delay, Colchester was reached. Owing to various difficulties no further progress was made until 1845, when the Eastern Union Railway Company was formed, and a direct line from Colchester to Ipswich was constructed under the superintendence of Mr. Bruff, Mr. Locke being the consulting engineer. The line was subsequently continued to Bury St. Edmunds and to Norwich. Mr. Bruff acted as Engineer and Manager to the Eastern Union Company, until in 1862 that and various other systems were amalgamated under the style of the Great Eastern Railway Company. Many of the branch lines and connections by which the present system was completed were planned by Mr. Bruff in the years following 1845; among them may be mentioned the Woodbridge extension, branches from Manningtree to Harwich, Bentley to Hadleigh, Bury St. Edmunds to Thetford, and Beccles to Tivetshall; the Tendring Hundred line from Colchester to Walton-on-the-Naze, with a branch to Clacton-on-Sea; and the Norwich and Spalding line. Although for a long time the struggle was an uphill one, the Great Eastern Company having at first mainly to depend on agricultural traffic, Mr. Bruff lived to see it establish a line of steamers to the Continent, develop a valuable connection through Lincoln with the North of England, and open out an enormous suburban traffic.

Mr. Bruff's work was not confined to railway engineering. At the time of the extension of the line to Harwich his attention was drawn to the lack of potable water in that town, and he undertook

to supply that deficiency; but it may be doubted whether he would have begun the task if he had had any idea of the difficulties to be encountered. His first attempt to get water was by deep boring at Harwich, which proved unsuccessful. Nothing daunted, he determined to pierce through the chalk, in the hope of obtaining water from the lower greensand, which he expected to find beneath. After boring for over 1,100 feet, however, carboniferous limestone was struck, and the well had to be abandoned. Mr. Bruff made a further attempt at Dovercourt, where he succeeded in obtaining a supply which lasted for some years. It was never quite satisfactory, however, in point of quality, and a third boring was made at Bradfield. This also proved unsuccessful, and the promoter was finally driven to Mistley, where he struck a good supply, which is now carried to Harwich, over a distance of 10 miles. In 1850, in conjunction with the late Mr. Hawkins, of Alresford, Essex, Mr. Bruff developed the works for the water-supply of Colchester, which some years later passed by purchase into the possession of the Corporation of that town.

For many years the gradual formation of a bar across the mouth of the Orwell and Stour estuaries was viewed with anxiety by all interested in the ports of Harwich and Ipswich. In 1844 £50,000 was granted by Parliament for the formation of a breakwater from Beacon Cliff, to divert the current towards Landguard Point, and also for dredging the shoals at the entrance to the harbour, in order that access might be afforded to first-class vessels. But the danger was not averted by the adoption of those measures, and, when Mr. Bruff was appointed Engineer to the Harwich Harbour Conservancy Board, about the year 1865, this was the problem he had to take in hand. After a full and careful study of the tidal currents, he designed and constructed a curved jetty at Landguard Point, which had the effect of completely destroying the bar, and, as a direct consequence, of preserving the ancient ports of Harwich and Ipswich, and of opening the way for the creation of Parkeston Quay.

In the development of many east coast watering-places Mr. Bruff took an active part. At Walton-on-the-Naze he constructed gas- and water-works, a pier, the Clifton Hotel and several lodging-houses. At Clacton-on-Sea he erected the pier and the Royal Hotel, and brought the town into communication with the Great Eastern Railway system. He also acted as Engineer for the Corporation of Ipswich in designing and carrying out the main drainage of the greater part of that town, and, at a later date, he was largely instrumental in the establishment, by

private enterprise, of a system of tramways through some of its principal streets. In his earlier days Mr. Bruff was an active member of the Royal Harwich Yacht Club, of which he acted for many years as Chairman of the Committee. Until recently he discharged his duties as Chairman of the Tendring Hundred Waterworks Company, and Engineer to the Harwich Harbour Conservancy Board, and was able to pay occasional visits to London. He died from natural decay at his residence, Handford Lodge, Ipswich, on the 24th February, 1900, in his eighty-eighth year.

Mr. Bruff, at the time of his death, was one of the oldest members of the Institution, having been elected an Associate on the 19th May, 1840, and transferred to the class of Members on the 8th April, 1856. In 1850 he contributed to the Proceedings a "Description of the Chapple Viaduct upon the Colchester and Stour Valley extension of the Eastern Counties Railway."[1]

GEORGE BRUNTON, fifth son of Mr. William Brunton, was born in Birmingham on the 29th January, 1823. At the age of 15 he joined his uncle, Mr. Robert Brunton, who was Manager of the Indian Iron and Steel Company's Works at Porto-Novo, India; and after his uncle's death he went to Beypoor, to which place the ironworks had been transferred, and remained there as Manager till the works were closed. He invented a cotton press, embodying a valuable improvement called the "extractor," by which the half-pressed bale is removed from the "half-press" to the "finisher," expediting greatly the whole process of compression. He also invented an hydraulic valve, and he was successful in irrigating by steam machinery vast tracts of rice land in southern India. Up to the year 1880 irrigation in that district had been accomplished by the slow and very inadequate means of native wheels.

Mr. Brunton died suddenly of failure of the heart at his residence, Ivy Lodge, Anerley, on the 28th March, 1900, at the age of 77.

He was elected a Member of the Institution on the 2nd December, 1862. In 1888 he presented a Paper entitled "An Experiment with a Steam-Exhauster or Blower."[2]

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[1] Minutes of Proceedings Inst. C.E., vol. ix. p. 287.
[2] *Ibid*, vol. xcii. p. 257.

GEORGE WORKMAN DICKSON, born on the 20th November, 1847, was educated at Trinity College, Dublin, where he became a Licentiate of Civil Engineering and took the degree of Bachelor of Arts in 1869. He was then engaged for four years on the construction of the Beccles Waterworks, the Chet Valley drainage and the Aldborough Waterworks. From 1873 to 1875 he acted as Engineer for Mr. Adalbert Müller, one of the contractors, on the construction of the Odessa Waterworks. He subsequently occupied a similar position on the contract for the Newbury District Waterworks, and was then for a time engaged on the construction of the Eastern and Midlands Railway in Norfolk.

Mr. Dickson's first appointment under the Colonial Office was in 1879, when he became Assistant Director of Public Works in the island of Trinidad. During his term of service in Trinidad he acted as Director of Public Works and General Superintendent of the Railways during the absence on leave of the Hon. J. Edward Tanner, besides sitting as a member of the Legislative Council. In 1891 he was appointed Colonial Civil Engineer in charge of the Public Works Department of British Guiana, and occupied a seat as one of the official members of the Court of Policy of that Colony since 1892. He was always careful in matters connected with the expenditure of public money, and it is believed that the strain put on him by the supervision of the railway extensions, in addition to the ordinary work of his department, assisted in undermining his constitution. During his period of office as Colonial Civil Engineer the railway system of British Guiana was increased from 20 miles to practically 95 miles. He also prepared recently with considerable pains an important report on a scheme for the drainage and irrigation of the Corentyne Coast. In public as in private life his career was above reproach. In the Court of Policy he was seldom heard, but when occasion arose for him to take part in a debate he was always a cogent speaker and his remarks carried considerable weight. Painstaking, thorough in his work, and courteous, he was esteemed by his staff, who fully recognised in him a capable and considerate chief. Mr. Dickson died at sea, on the voyage to England, on the 10th June, 1900.

He was elected an Associate of the Institution on the 7th May, 1878, was subsequently placed in the class of Associate Members, and was transferred to the class of Members on the 23rd January, 1894.

ROGERS FIELD, eldest son of Mr. Edwin Wilkins Field, solicitor, of London, was born in 1831, and was educated at University College School and University College, Gower Street, and graduated B.A. London. He was articled in 1853 to Mr. Thomas Wicksteed, under whom he was engaged on the Leicester sewerage and the Scarborough waterworks. From 1859 to 1864 he was employed on drainage and reclamation works for Mr. Bailey Denton; and since the latter year he was in practice in Westminster—at first alone and latterly in partnership with Mr. A. T. Bean—as an Hydraulic and Drainage Engineer.

Mr. Field's work was characterized by thoroughness and attention to detail; the science and practice of hydraulics had a peculiar fascination for him, and he was never so happy as when making, in the experimental laboratory attached to his offices, hydraulic investigations involving minute accuracy. He devoted himself with great energy to the practical application of the principles governing the sanitation of buildings, and did much to raise this important subject to a scientific level. The by-laws and regulations for house drainage framed by him in 1876 for the town of Uppingham were among the first of the kind; they attracted considerable attention, and were substantially adopted by the Local Government Board in their model by-laws of 1877 as to house drainage.

Mr. Field designed and superintended the construction of the water-supply, drainage, and sewage disposal arrangements of a number of public institutions, hospitals, asylums, schools and private residences throughout the country, including the drainage of Sandringham House and Bagshot Park. He was interested in the question of the drainage of agricultural land, and also in that of sewage disposal, and was in favour of sewage purification by application to land wherever practicable, by broad irrigation either over porous land or over specially prepared filtration-areas well underdrained. He was the inventor of Field's engineering aneroid-barometer, having an adjustable scale which takes into account the variable temperature of the air. The principle of adjustment is that of shifting the altitude-scale according to the temperature of the air, and the scale having been set according to the temperature likely to prevail during the observations, it will be found that the readings will give at once the differences of elevation with great accuracy. In all questions relating to meteorology he was particularly interested, and paid much attention to rainfall, evaporation and percolation, and the movement of underground water, on which he contributed some valuable chapters to a work entitled, "Our Homes, and how to make them

Healthy," published in 1883. He drew up in 1892 a pamphlet issued by the Commissioners in Lunacy, entitled "Practical suggestions as to water-supply, drainage, and sewage disposal for Lunatic Asylums," as a guide to Engineers and Surveyors having to deal with such matters.

Mr. Field carried out an extensive series of experiments on the working of siphons, resulting in the particular form of annular self-acting siphon which he invented and brought to a high standard of perfection. These siphons have, from their reliability in action, been very extensively used for flushing purposes in drainage and sewerage works in this country, and also in many places abroad, particularly in America, where they have been adopted in conjunction with the Waring system of sewage disposal of isolated establishments by means of a siphon-tank and sub-irrigation drains.

Mr. Field took great interest in the Parkes Museum of Hygiene and the Sanitary Institute, of the Council of which body he was an active member. For many years he was engaged in carrying out for that Institute an exhaustive series of experiments on air meters, cowls and terminals. He was one of the Judges at the International Medical and Sanitary Exhibition of 1881, and was on the Committee of the International Health Exhibition of 1884, and prepared the sections of the "Handbook on the Water-Supply and Disposal of Sewage of Country Houses," published by the Executive Council of that Exhibition.

Mr. Field died at his residence, Squire's Mount, Hampstead, on the 28th March, 1900, aged 68.

He was elected an Associate of the Institution on the 9th January, 1866, and was transferred to the class of Members on the 29th May, 1877.

JOHN VIRET GOOCH,[1] who died on the 8th June, 1900, at his residence, Cooper's Hill, Bracknell, Berks, was one of the last two or three remaining pioneers in railway locomotive engineering. Mr. Gooch had reached the ripe age of 88, and had retired from active business quite forty years ago, so that to all but a few of the present generation of engineers he was unknown, except for the excellent work he did and the influence he exerted in the evolution of the locomotive of to-day. In this connection, indeed, he deserves to be remembered with Trevithick, the Stephensons, his

[1] This Notice, with some slight modification, has been reproduced, by permission of the Editors, from *Engineering*, 15th June, 1900.

brother—Sir Daniel Gooch—Brunel, Locke, Sinclair, Ramsbottom, Allan, and others who need not be named. It was under Locke, when at his years of greatest energy and initiative, that Gooch served his pupilage, and during part of the time, away back in the thirties, he was engaged in the construction of the Grand Junction Railway, for which Locke was Engineer.

In view of Mr. Gooch's practice in later years, it is worth recalling that it was while he was with Locke that the latter re-introduced into favour the outside cylinder arrangement. The Grand Junction Railway was opened in 1837, and the first locomotives had inside cylinders; but when it became necessary to refit the engines, the cylinders were placed outside, so that by 1851 this type became the standard locomotive of the line. Gooch was occupied on this work, and continued it during the three years he held the position of Resident Engineer on the Grand Junction Railway. Early in the forties he became Resident Engineer on the London and South-Western Railway, and for ten years had entire charge of the Locomotive Department. He resigned this position to serve in a similar capacity for the Eastern Counties—now the Great Eastern—Railway, retiring, as has been said, over forty years ago.

It is scarcely necessary to recall that during his later years on the South-Western Railway, and the earlier years of his service on the Eastern Counties Railway, controversy was active as to inside and outside cylinders, and as to the relative advantages of great deadweight, as compared with light, locomotives. Most of the heavy railway haulage was done then—about the year 1849—by engines having inside cylinders, and 30 tons was by no means an uncommon weight; but Gooch held the view that engines with large driving wheels, and of which the weight was moderate and about equally distributed on all the wheels, gave results as good, both as regards economy and speed, as could be realized with the heavier locomotives then more largely in vogue. With this arrangement he combined outside cylinders, inclined to clear the leading wheels, which were thus placed behind the cylinders, the drivers being before, and the trailers behind, the firebox. The original South-Western locomotives made in 1838 had inside cylinders, the first outside cylinders being applied by Gooch in 1843, and his first engine of this type had 6 feet 6-inch driving wheels—the first locomotive with drivers over 6 feet (except Dr. Church's[1] 6 feet

[1] A drawing of Dr. Church's London and Birmingham Steam Coach may be found in the Library Inst. C.E., Tracts 4to. vol. 73.

2½ inches), to be run on a railway of 4 feet 8½-inch gauge. Within a few years, too, Gooch increased the size of his express-engine driving-wheels to 7 feet. Their success was marked, for they "struck a mean" between the very light locomotives which William Bridges Adams built for some lines about this time, and the much heavier types. The former, in fact, known as the "Express," never came within the range of practical application, whereas Gooch's design, especially as embodied in the "Snake" class, and subsequently developed in the tank engines built by him when on the Eastern Counties Railway, for working the Tilbury traffic, had a permanent influence on later locomotive practice.

Gooch's "Snake" class was, in fact, a famous type in the earlier days of locomotive practice. The original engine built by Gooch when on the London and South-Western Railway was a six-wheeled engine with driving-wheels 6 feet 6½ inches in diameter, and leading and trailing wheels 4 feet ½ inch in diameter, the wheel-base being 12 feet 8½ inches, and the total weight in working order only 19 tons. It is noticeable that of this weight only 6 tons rested on the drivers, while the load on the leading wheels was 8 tons. In the tank-engines subsequently built, to which reference has already been made, the addition of rear-tanks and the extension of the foot-plate, gave a better distribution of the load. The "Snake" had cylinders 14½ inches in diameter with 21-inch stroke, and the slide-valves were fitted with back-plates arranged to admit steam through the valves as well as past the ends as usual, the effect of double ports being thus obtained. There were also other special features about the "Snake;" the pumps were driven by eccentrics forged solid on the driving-axle, the firebox was fitted with a mid-feather made of corrugated plates, and the boiler was fitted with Gooch's combined pressure-indicator and safety-valve, which was the predecessor of the modern pressure-gauge. This indicator consisted of a short brass cylinder of 1 square inch area fitted with a piston loaded by a helical spring. The steam-pressure acted on the under side of the piston and forced it upwards, the pressure being shown by a finger on the piston-rod moving against a graduated scale. On the piston being raised above a certain distance it uncovered a port through which the steam could escape, the arrangement thus constituting a safety-valve. The "Snake" had 12·4 square feet of grate surface, 898½ square feet of heating surface, and the boiler pressure was 80 lbs. During some trials of the engine made in September, 1848, on the South-Western Railway with a train weighing 17½ tons, the engine attained an average speed of 51¼ miles per hour, excluding stoppages (or 41·4

miles per hour with stoppages included), on a consumption of 23·2 lbs. of coke per mile, the water evaporated being given as 8·9 lbs. per pound of coke.

Reference has already been made to the tank locomotives built by Gooch for the Tilbury traffic. These were successively built in three different sizes, with 11-inch, 12-inch, and 14-inch cylinders respectively, the boilers being also successively enlarged. Of the second-sized type, which had 12-inch cylinders with 22-inch stroke, and weighed in working order 23¾ tons, of which 9 tons rested on the drivers (6 feet 6 inches in diameter), some trials were made in 1853 between London and Norwich, when it was found that the water evaporated per pound of coke was 8·5 lbs., and the consumption of coke per mile from 15·1 lbs. to 15·5 lbs. The train-load was 45·6 tons, and the mean speed—including eight or nine stoppages on the 259 miles run—about 37 to 37½ miles. In two cases, however, with a train of 68 tons, speeds of 46 and 43·3 miles an hour were obtained, the steam-pressure being 105 lbs. and 100 lbs. instead of 84 lbs. These results, even in the light of the 47 years' progress since made, are distinctly satisfactory; although, after all, experience went to show that, while there might be commercial advantage in the diminution of relative weight, the light locomotive as an engine worked at a decided disadvantage, and that in proportion to the effective horse-power exerted, the larger sizes, if of equally good design, structure and management, worked at a less cost for fuel, repairs and attendance than the light engines.

Mr. Gooch afforded another instance of commercial success prematurely robbing engineering science of an able and experienced worker, for he did little practical work during the past forty years, enjoying country life in his Berkshire home. While engaged in the work of railway locomotion he applied himself diligently to his business, and although he was elected a Member of this Institution on the 2nd May, 1854, he only spoke on two occasions, once on the treatment of water to suit it for locomotive use, giving results of the experimental use of many chemical solvents,[1] and again on his favourite subject of light *versus* heavy engines.[2] By those who knew him his memory will be cherished, and for his services to locomotive engineering he will always be respected.

[1] Minutes of Proceedings Inst. C.E., vol. v., p. 195.
[2] *Ibid*, vol. viii., p. 244.

EDWARD PRITCHARD was born at Wrexham on the 13th September, 1838. His early professional life was spent in survey and railway work in this country and in Australia. In 1865 he became Borough Surveyor of Clitheroe, and held that post until June, 1870, when he was appointed Borough Surveyor to the Corporation of Warwick. There he induced the Corporation to adopt his scheme for a sewage farm, and at the same time a joint Drainage Committee for the districts draining into the River Tame was formed. He also took in hand the provision of a water-supply for Warwick, and his scheme, by which the water was brought by gravitation from Haseley Brook, near Haseley Mill, was successfully carried out. The Warwick and Leamington Tramway was also laid down by Mr. Pritchard. At Clitheroe and at Leigh, he had organised volunteer fire brigades, of which he acted as captain. Soon after he took up his residence at Warwick he became lieutenant of the Volunteer Fire Brigade there, and in that capacity was present at the great fire at Warwick Castle in December, 1871.

In 1876 Mr. Pritchard resigned his appointment at Warwick and commenced independent practice, with offices in Birmingham and in London. Over a hundred towns in Great Britain have been provided by him with waterworks, sewerage or tramways. The Wolverhampton Corporation was one of the many public bodies which sought his assistance in the matter of sewage disposal. In August 1888, he went to South Africa, to report for the municipality of Cape Town, on the best means of sewering the district and disposing of its sewage. This led to his being retained by the municipalities of Woodstock, Claremont and Wynberg, important districts closely adjoining Cape Town. While waiting for surveys to be completed at Cape Town he visited the diamond fields of Kimberley, and the goldfields of the Transvaal. At Kimberley he was able to give some important advice to the authorities on the question of sewage disposal, and at Johannesburg, then just rising into importance, he received instructions to prepare a scheme which should supply water for gold-washing at the mines, as well as for domestic purposes in the town. The waterworks which supply the town of Pretoria were designed by him, and the fittings were sent from this country under his supervision. A water company at Klerksdorp also carried out under his advice a scheme for supplying the town from a point in the Vaal River, 8 miles distant.

As a tramway engineer, Mr. Pritchard was associated with many notable undertakings. One of the earliest of those enterprises was that at Magdeburg. In 1886, when he was acting as Engineer to

the then Birmingham Central Tramways Company, he took part, with Mr. Joseph Kincaid, in designing and carrying out the cable tramway. He prepared himself for the work by making exhaustive enquiries in the United States into the various systems of working cable tramways there, and came back thoroughly convinced that this was the most economical form of street locomotion which had then been put into practice. He recommended its adoption both on the Handsworth route and on the Bristol Road, the control of these routes having just been taken over by the Central Company from the old Birmingham Tramway and Omnibus Company. The Handsworth line was reconstructed on the cable system, and it is largely due to the care and skill exercised by Mr. Pritchard that the work was carried out in such a way that the Handsworth tramway service is still the most efficient and profitable in the city and neighbourhood. Among other tramway systems carried out by Mr. Pritchard are those at Leamington and Warwick, Barrow, Dudley and Stourbridge.

Some years back, Mr. Pritchard was engaged in the development of gold mines in Silesia under the Austro-Hungarian Government. In 1896 he was retained by a syndicate for exploitation of the then newly-opened goldfields of British Columbia. He spent some time there prospecting on behalf of the company, and took advantage of his visit to make some observations on the tramways of the Canadian cities.

Mr. Pritchard was a Member of the Incorporated Association of Municipal and County Engineers, of which body he acted as President in 1879–80; he was a Fellow of the Geological Society, a Member of the Royal Meteorological Society, a Member of Council of the Sanitary Institute of Great Britain, and a Member of the North of England Institute of Mining and Mechanical Engineers. He was also a prominent Freemason. Mr. Pritchard was married to a daughter of the late Lieutenant-Colonel John Stenson, of the 1st Dragoon Guards, who survives him. He died at his residence, Park Mount, Selly Oak, Birmingham, on the 11th May, 1900.

Mr. Pritchard was elected a Member of the Institution on the 6th May, 1884.

RICHARD REYNOLDS ROWE, born in Cambridge on the 5th June, 1824, was educated at Eaton-Socon and at Cambridge. He became acquainted in 1847 with Mr. Ewan Christian, for whom he

acted as clerk of the works during the building of St. Thomas's Church, Douglas, Isle of Man. In the following year he was engaged on drainage works and well-boring in Essex, and in 1850 he was appointed Engineer to the Improvement Commissioners of Cambridge, which post he held until 1869. In addition, he performed from 1852 the duties of Surveyor of Bridges and Public Works in the Isle of Ely, and from 1856 those of Engineer to the March Board of Health. From 1850 he also practised on his own account in the town and county of Cambridge and in the Isle of Ely. For many years he acted as architect to the Cambridgeshire and Isle of Ely Asylum, in connection with which he carried out extensive works. He was also permanent Clerk of the Works at Ely Cathedral, and was frequently consulted as to the restoration of churches in the county of Cambridge. Mr. Rowe died at his residence, Park House, Cambridge, on the 21st December, 1899, at the age of 75.

Mr. Rowe took active interest in local affairs, being for some years a Member of the Town Council, of the Improvement Commission, and of the Board of Guardians. He was a Knight of Justice of the Order of St. John of Jerusalem, and took considerable part in the formation of the body now known as the Church Congress. At the time of his death he was President of the Institute of Sanitary Engineers, and a Fellow of the Royal Institute of British Architects, of the Surveyors' Institution, and of the Society of Antiquaries. His disposition was kind and benevolent, his intellect strong, and his energy untiring.

Mr. Rowe was elected an Associate of this Institution on the 4th December, 1855, and was transferred to the class of Members on the 29th March, 1859.

CHARLES STONE,[1] born at Bath on the 3rd October, 1820, early displayed a talent for mechanics and drawing. At the age of 16 he entered the office of Mr. Luke Herbert, engineer, with whom he served several years, first in London and subsequently in Birmingham. At the commencement of what was then termed "the railway mania," he entered the office of Captain W. S. Moorsom, in Great George Street, Westminster, under whom he was engaged in making designs and working drawings and

[1] This notice is largely autobiographical.

estimates for the Southampton and Dorchester, West Cornwall, and Waterford and Kilkenny lines. In January, 1857, he went to Ceylon on Captain Moorsom's staff for the survey of the Ceylon Government Railway from Colombo to Kandy; and at the end of 1858 he was appointed a District Engineer in the service of the Scinde, Punjab and Delhi Railway Company, and entrusted with the task of selecting the executive staff for that line from Mooltan to Lahore and Umritsur. On the completion and opening to traffic of that line in 1865, he was posted to a section of the Delhi line between Umballa and Meerut. In 1870 he was appointed Chief Engineer to the Company, and held that post until 1881, when ill health obliged him to resign and return to England. Three years before, he had received the thanks of the Government of India for his "great personal exertions in restoring through communication on the line over two large breaks near Jullundhur."

From the year 1881 Mr. Stone lived in retirement, his health not admitting of his undertaking professional employment. He died at his residence, Dalhousie, Outram Road, Addiscombe, on the 20 April, 1900.

Mr. Stone was elected a Member of the Institution on the 2nd February, 1864. In 1874 he contributed to the Proceedings a Paper entitled "The Implements Employed, and the Stone Protection Adopted, in the Re-construction of the Bridges on the Delhi Railway." [1]

CHARLES MORRIS JENKINS, third son of Mr. Thomas Jenkins, J.P., of Pantyscallog, Dowlais, was born on the 9th October, 1866. He received his early training at the Dowlais Ironworks, where he was subsequently engaged for nearly six years. In 1889 he entered the service of the Natal Government, and was first engaged on the survey for a railway proposed to be made between Verulam and Stanger. At the beginning of 1891 he was transferred to the construction staff of the Van Renen Pass—Harrismith section of the Natal-Orange Free State Railway, which work was completed in July, 1892. Mr. Jenkins was next engaged on a scheme to supply the town of Harrismith with water, which work he saw successfully carried through. He was then employed as contractor's engineer on a section of the Delagoa Bay Railway, where, however, his robust health was not proof against the all-prevalent malaria; but, notwithstanding repeated attacks of fever, he remained at his

[1] Minutes of Proceedings Inst. C.E., vol. xxxix. p. 212.

post till the completion of the contract, and after recruiting his health in Natal, he was able to take up work in March, 1894, on the staff of the Natal Government for the construction of the Charlestown-Johannesburg Railway. Mr. Jenkins was placed in local charge of the Paardekop-Standerton section, and displayed great energy in carrying out the work on his section. In June, 1896, he was appointed to the contractor's staff of the Pretoria Pietersburg Railway. He had to conduct a survey under very trying circumstances, owing to horse sickness, rinderpest, drought, and consequent famine in that part of the Transvaal. It was no unusual thing for the party to be without adequate food, and water, even then very bad, could only be obtained at great distances. Mr. Jenkins, however, with characteristic determination proved equal to the occasion, for when his cattle and horses died, and after trying mules with little better success, he continued the work on foot, often walking long distances to and from camp. After the survey he was engaged on the construction, first on the comparatively healthy portion of the line at the Pretoria end, and afterwards in the more unhealthy neighbourhood of Pietpotgieters Rust, where the resourcefulness he had shown on the survey had to be repeated. On the completion of the line to Pietersburg Mr. Jenkins obtained the contract for a section of the Machadodorp-Ermelo Railway, also in the Transvaal, on which he was engaged at the time of the outbreak of hostilities. The works coming to a standstill in consequence of the war, he proceeded to Natal, and having had some training as a volunteer at home, he was successful in obtaining a commission as lieutenant in Thornycroft's Mounted Infantry. He fell at Colenso on the 15th December, 1899. His cheerful disposition and love of all manly sports made him many friends, and his memory will be cherished most by those who knew him best, and will long remain green in Natal.

Mr. Jenkins was elected an Associate Member of the Institution on the 16th May, 1893.

THOMAS NUTTALL, born at Bury on the 20th February, 1838, was educated at the Grammar School in that town. In 1854 he was articled for five years to Messrs. Gorton and Cross, of Bury, mining engineers and surveyors, in whose employment he subsequently remained. In 1863 he commenced business on his own account in Broad Street, Bury. Among the works on which Mr. Nuttall was employed may be mentioned the surveys for the

Sheffield, Buxton and Liverpool Railways, the Lancashire Union Railways, for the waterworks at Stockport, Sheffield, Sunderland, Nottingham, Wakefield, Derby, Newcastle and Gateshead, Matlock and Newark, and for Moston Colliery, North Wales. He acted as Land Steward for the Trustees of Bury Grammar School, and as Surveyor to the District Councils of Kearsley, Ramsbottom and Prestwich. He had considerable practice in Lancashire in arbitration cases and as a Parliamentary Surveyor. Mr. Nuttall was a Fellow of the Surveyors' Institution, a Member of the Incorporated Association of Municipal and County Engineers, and in 1889 President of the Manchester District Society of Surveyors, Land Agents and Valuers. He died at his residence, Fernsholme, Bury, on the 6th May, 1900.

Mr. Nuttall was elected an Associate of the Institution on the 7th May, 1872, and was subsequently placed in the class of Associate Members.

FREDERICK WILLIAM STEVENS, C.I.E., born at Bath in 1848, began his professional career as a pupil in the office of Mr. Charles Edward Davis, engineer and architect, and Surveyor of Works to the Corporation of Bath. As the result of competitive examination he was appointed in 1867 to the Public Works Department of the Government of India as an Assistant Engineer. He was attached to the office in Bombay of the Architect to Government, General Fuller, R.E., and at the close of 1868 was transferred to the office of the Architectural Executive Engineer and Surveyor. In 1876 he was appointed Government Examiner to the Bombay School of Art, and in the following year his services were placed at the disposal of the Great Indian Peninsula Railway for the purpose of designing the terminal station at Bori Bunder, which is a fine example of his creative skill. This terminus, which is stated to be the largest building erected in Asia in modern times, was constructed in 1879 under his superintendence, and his public services were acknowledged by his being elected a Fellow of Bombay University.

Mr. Stevens retired from the Public Works Department in 1884, and in 1888 he was selected by the Corporation of Bombay to design and superintend the erection of the great pile of Municipal Buildings in that city. In the following year he was created a Companion of the Order of the Indian Empire "for services rendered in connection with public buildings in Bombay."

He also designed the administrative offices of the Bombay, Baroda and Central India Railway, the Royal Alfred Sailors' Home, the Post Office mews on the Apollo Bunder, the Government House at Naina Tal, and several other buildings. Mr. Stevens was a Fellow of the Royal Institute of British Architects, and he secured medals for architectural and engineering designs at the Bombay Exhibitions of 1872 and 1879; indeed he may be said to have contributed towards the embellishment of that city much that is best in its architectural beauty. Mr. Stevens died at his residence, Nepean Road, Malabar Hill, on the 5th March, 1900, aged 52. He was an artist in the true sense of that term; his profession was not merely the labour, it was also the delight of his life; and even when on leave he was not happy unless accompanied by his drawing-board.

Mr. Stevens was elected an Associate of the Institution on the 5th December, 1871, and was subsequently placed in the class of Associate Members.

JOHN THOMPSON, born at Woodley, Cheshire, on the 21st March, 1846, was educated at Knutsford Grammar School. After serving articles to Mr. M. A. Roscoe, of Altrincham, he was appointed in 1866 Surveyor to the Warrington District Highway Board, in which post he was continued when the Board gave place to a Rural District Council in 1899. During the thirty-three years he held that office Mr. Thompson carried out great improvements in the roads of the district, and several bridges were constructed from his design and under his supervision. He took great interest in the details of his duties, and succeeded in organizing a band of good workmen who maintained the highways in an excellent state of repair. Mr. Thompson died at The Mount, Orford, Warrington, on the 16th February, 1900, at the age of 53.

He was elected an Associate Member of the Institution on the 7th February, 1893.

JOHN HENRY JOHNSON, senior partner in the firms of Johnsons and Willcox, patent agents, and J. H. and J. Y. Johnson, solicitors, died at his residence, Mountains, Tonbridge, on the 12th March, 1900, in his 73rd year.

He was born in Kendal and was articled to a solicitor in that town. Ultimately he started in London as a solicitor and patent agent, the latter business being originally intended as an offshoot of a patent agency business carried on in Glasgow by himself and one of his brothers, but the London business became the principal one. Mr. Johnson was concerned as solicitor in some of the most important patent cases of the last forty years. In conjunction with his elder brother, Mr. James Yate Johnson, who was a Barrister of the Middle Temple, he produced the "Patentees Manual," which is well known as a valuable compendium of Patent Law, and for some years he was the proprietor of "The Practical Mechanics Journal." Mr. Johnson was the first President of the Patent Agents' Institute. He suffered from a severe and painful illness during the last twelve years of his life, and was compelled to withdraw from active participation in business and to live entirely at home.

Mr. Johnson was elected an Associate of the Institution on the 2nd May, 1865.

*** The following deaths also have been made known since the 15th May, 1900:—

Members.

FORMAN, JAMES RICHARDSON; *died* 8 July, 1900.
LAW, HENRY; *died* 18 July, 1900.
LINDLEY, WILLIAM; *died* 22 May, 1900.
LITTLE, THOMAS DAVID, C.I.E.; *died* 16 May, 1900.
MORTON, ANDREW; *died* 3 June, 1899.
PROCTOR-SIMS, RICHARD; *died* 31 May, 1900.
REILLY, *Professor* CALLCOTT; *died* 21 May, 1900.
ROBERTSON, ROBERT ANDREW; *died* 1 June, 1900.
SMITH, HAMILTON; *died* 4 July, 1900.
WILSON, JAMES; *died* 21 July, 1900.
WINGATE, ROBERT; *died* 18 June, 1900.

Associate Members.

BARCLAY, ARTHUR; *died* 17 May, 1900.
BOLD, EDWARD HENRY; *died* May, 1900.
DAVIS, FREDERICK; *died* 14 July, 1900.
HUGHES-HALLETT, CHARLES FREDERICK, M.A. (*Cantab.*); *died* 22 June, 1900.
OWEN, THOMAS ELLIS; *died* 5 June, 1900.
SMITH, WILLIAM WARREN; *died* 17 March, 1900.
STORRS, HUBERT TOWNSEND, B.Sc. (*Victoria*); *died* 19 May, 1900.

Associates.

BARRY, CHARLES; *died* 2 June, 1900.
McILWRAITH, *Sir* THOMAS, K.C.M.G., LL.D. (*Glas.*); *died* 17 July, 1900.
MORGAN, JOSEPH BOND; *died* 20 April, 1900.

Information as to the career and characteristics of the above is solicited in aid of the preparation of Obituary Notices.—SEC. INST. C.E., 28 July, 1900.

Sect. III.

ABSTRACTS OF PAPERS IN SCIENTIFIC TRANSACTIONS AND PERIODICALS.

The Block System for Single Line Railways. M. Boda.

(Organ für die Fortschritte des Eisenbahnwesens, 1899, p. 328.)

On the Austro-Hungarian Railway system, by far the greater part of which consists of single track, the system of working the traffic by preserving an interval of space between succeeding trains has lately been introduced.

The problem was thus presented of carrying out a block system at once economical and efficient, and to arrange it to work in with the existing signal work at the stations.

The Author in this Paper describes the method proposed by L. Kohlfürst and distinguished by the word "Natalis." The existing station cabins are left without much alteration, a new cabin being erected at each station, together with intermediate ones varying in number according to the amount of traffic.

The old cabin at each station is connected electrically with the new station cabin and receives instructions from it, but is not in communication with any other cabin. The block system is thus worked entirely by the new cabins, and one special feature of the system is the use of electric current through the rails, the circuit for which is only made by a passing train.

The Author takes the case of a length of single line between two stations divided into three block sections, and describes in detail the operations required first for trains following one another, and then for reversing the direction of the traffic. He then compares this system with another proposed by Mr. O. Walzell, and concludes with some considerations as to the advantages of constructing passing stations when the traffic becomes very dense over the method of increasing the number of block sections between stations.

W. B.

Nickel Steel Rails in the United States.

W. H. Brown, Chief Engineer, Pennsylvania Railroad.

(Railroad Gazette, New York, 1900, p. 195.)

On June 26th, 1899, the Pennsylvania Railroad placed an order with the Carnegie Steel Company for 300 tons of steel rails to contain 3 per cent. of nickel. The material was made by the

Bessemer process and rolled to the American Society pattern 100-lb. section the last week in July, 1899; but the nickel content caused "red-shortness" to such an extent that the rolling resulted in only 220 tons of No. 1 and 57 tons of No. 2 rails, and 19 tons of the latter had to be rejected on account of "piping." The average analysis was: carbon, 0·504 per cent.; phosphorus, 0·094 per cent.; manganese, 1 per cent.; and nickel, 3·22 per cent. Under the straightening presses the rails showed great rigidity; twice the force ordinarily used being required to accomplish the cold straightening, and often the rail would spring back to its former position after being struck, showing no effect of the blow. In drilling the hardness was even more marked; in some cases five twist drills of ordinary tool-steel being used up in drilling one hole. After experimenting with different materials for drills, it was found the best results were obtained by using Mushet steel without lubrication. These rails are laid on the west track on the Horse Shoe curve, but they have not been in service long enough to enable much to be said about their wearing qualities.[1]

F. G. D.

Train Resistance. A. Frank.

(Organ für die Fortschritte des Eisenbahnwesens, 1899, p. 146.)

The total resistance on a straight level road is made up of two parts, viz. (1) that independent of the wind pressure and (2) that portion arising therefrom.

The first may be put equal to μQ, where μ is a constant, the value of which is to be obtained from experiment; Q is the weight of the locomotive or vehicle. The second may be put in the form $\lambda F v^2$, where λ is a constant, F the "equivalent" surface exposed to the wind, and v denotes the speed.

It is clear that the plane surface which would have the same resistance on account of wind as the locomotive actually experiences must be smaller than the projected surface of the locomotive seen from the front. But the constant λ is taken the same as for a flat surface, to allow for the increase of the resistance to the motion of the train arising from the imperfection of the rolling surface.

To determine the values of the various constants the Author arranged a series of experiments with trains on a long incline, allowing them to attain, without steam, their full speed—being that due to gravity alone.

[1] In an editorial note, at p. 202 of the same issue, it is mentioned that Mr. Cushing, of the Cleveland and Pittsburgh division of the same railway, recently stated that after 2 years' service nickel steel rails laid in that division showed hardly any wear, and were standing up better than any other rails.—F. G. D.

The values for μ were as follows:—for four-coupled passenger engines, 0·0032; for six-coupled goods engines, 0·0038 to 0·0039; for wagons, 0·0025.

For the term containing the square of the velocity the area F was found to be 7 square metres (75·35 square feet) for passenger engines, and 8 square metres (86·1 square feet) for goods engines.

The vehicles following the locomotives are of course sheltered to a large extent from the force of the wind, but the spaces between them permit of this taking effect to the extent denoted by the following equivalent surfaces:—

Baggage wagon	1·7 square metre	(18·3 square feet).
Passenger carriage or covered goods wagon	0·5 „ „	(5·38 „ „).
Open wagons, loaded . . .	0·4 „ „	(4·3 „ „).
„ „ empty . . .	1·0 „ „	(10·76 „ „).

Every carriage or covered goods wagon following an open goods wagon adds 1 square metre (10·76 square feet) to the total effective surface.

The Author goes on to derive simple methods of using the data obtained by him; principally by introducing average values of F, etc. He then compares and criticises certain other formulas with the view of showing that his method is the only rational one, and that attempts to obtain a simple formula to suit all cases must end in failure.

W. B.

Acceleration of Trains. F. Lackner.

(Organ für die Fortschritte des Eisenbahnwesens, 1899, p. 209.)

The Author first obtains the following formula for the average work per second performed by the locomotive against the frictional resistances and the gradient,

$$A^{\frac{\text{kg. m.}}{\text{sec.}}} = \frac{Q^t\, V^{\frac{\text{km.}}{\text{hour}}}}{7 \cdot 2}\left[\mu^{\frac{\text{kg.}}{\text{ton}}} \pm 1{,}000 \sin a\right],$$

in which Q^t = weight of train, V the speed in kilometres per hour, μ the resistance per ton weight of train, a the angle of inclination of the track.

From this the force exerted is equal to—

$$K^{\text{kg.}} = \frac{Q^t}{2}\left(\mu^{\frac{\text{kg.}}{\text{ton}}} \pm 1{,}000 \sin a\right).$$

If the actual horse-power exerted by the locomotive is put equal to $N^{\text{P.S.}}$, the corresponding tractive force is—

$$Z^{\text{kg.}} = 270\, \frac{N^{\text{P.S.}}}{V^{\frac{\text{km.}}{\text{hour}}}}.$$

The excess of Z over K gives the accelerating force—

$$P = 270 \frac{N^{\text{P.S.}}}{V^{\frac{\text{km.}}{\text{hour}}}} - \frac{Q^t}{2}\left[\mu^{\frac{\text{kg.}}{\text{ton}}} \pm 1{,}000 \sin \alpha\right].$$

The only quantities in this formula not directly measurable are the horse-power and the train-resistance.

To arrive at the horse-power the Author gives two methods, depending on (*a*) the speed of running and the heating surface of the boiler; (*b*) the boiler-pressure and ratio of expansion, tables being given for use with this latter method.

To determine the train-resistance, the Author uses the formula of the German Railway Union. In order to test his theoretical results, the Author ascertained by experiment the actual times taken by trains in getting up speed, and on comparing these with the values derived from using his formulas he found that there was practically no difference.

The logs of two journeys—from Vienna to Trieste and back—are given in tabular form at the end of the Paper.

W. B.

Fortifications and Local Railways. Welitschko.

(Mittheilungen über Gegenstände des Artillerie- und Genie-Wesens, 1899, p. 161.)

The Russian Author divides fortifications into three groups, namely, those defending depôts for war material, important strategical points, or, in short, forming bases for armies in the field; less important works, designed to defend mountain passes or command roads or railways; and those situated on a coast line and liable to attack on the sea side only, or on both sea and land sides.

The principles governing the general design, extent, and armament of each type of fortress are discussed, and in particular, in the case of a ring or girdle of permanent forts, the importance of mounting heavy guns in the intervening spaces is insisted on. Particulars are given of the number, character, and location of the guns considered necessary to defend a fortress of the first class and of the supply of ammunition thereto.

Considerable space is devoted to the design and use of railways in and about fortifications. At first only portable systems were used, from 50 centimetres (1 foot 8 inches) gauge upwards, but now permanent lines are laid and supplemented by portable branches.

Great stress is laid upon the necessity of the branches being the same gauge as the permanent lines, and a comparison, based on the results of experiments, is given of the time occupied in transporting a complete battery of four 6-inch guns, 4 kilometres to 5 kilometres ($2\frac{1}{2}$ miles to 3 miles), with and without a break of gauge. In the former case the time taken would occupy 4 hours

to 4 hours 4 minutes, as against 1 hour. Uniformity of gauge carries with it the use of a narrow gauge, but the Author shows that there is little objection to this. The main line entering a fortress will, of course, be standard gauge. The Author concludes that for Russia a 75-centimetre (2·46 feet) gauge is the best.

A plan is given of a railway system for a first class fortress; the lines have a length of 106·7 kilometres (66¼ miles). The rolling-stock requirements, estimated on the basis of placing 100 guns in position in a single night, are, including reserve, given as nineteen locomotives and 290 wagons. The total cost is given as 1,650,000 rubles (£165,000),[1] or 16,500 rubles per verst (£4,490 per mile) with a gauge of 75 centimetres (2·46 feet). On a war footing the necessary personnel is put at 17 officers, 706 trained men and 446 labourers; in time of peace, at 4 officers and 60 men.

The Paper concludes with an account of experiments carried out between 1892 and 1897, on the transport of guns and material under varying conditions, and is accompanied by two plates.

W. B.

Cost of Heating Railway Carriages with Steam. R. Kluge.

(Organ für die Fortschritte des Eisenbahnwesens, 1899, p. 222.)

This article commences by showing how it is possible to arrive at the cost of heating carriages by steam without the necessity for special tests, but simply by calculation from the returns relating to the number of miles run by each locomotive, the length of time under steam, the number of axle-miles for goods and passenger trains, and the amount of fuel consumed.

The general principle is as follows:—Let γ = the average coal consumption per axle-mile for goods trains during the winter months, ν ditto for the summer months; further let γ_1 and ν_1 denote the corresponding quantities for passenger trains.

Put $$\gamma - \nu = \delta,$$

and $$\gamma_1 - \nu_1 = \delta_1.$$

Then $\delta_1 - \delta$ gives, after making certain corrections, the coal consumption representing the cost of heating per axle per mile.

The Author's method has been tested and found to give correct results.

Tables are given showing the coal-consumption for the heating by steam of the carriages on the main lines of the railways of Saxony during the winter months of 1894–95. The average was about 4½ lbs. of coal per axle per hour for the six winter months,

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[1] The value of the ruble is taken at two shillings.

and 6½ lbs. for the three coldest months, the coal being of such a quality that it produced seven and a half times its own weight of steam in the locomotive boiler.

W. B.

Super-elevation and Slackening of Gauge on Railway Curves.

J. SANDNER.

(Organ für die Fortschritte des Eisenbahnwesens, 1899, p. 238.)

This article gives the history of the various efforts made by the German Railway Union to settle the questions of super-elevation and slackening of gauge on curves. Since the year 1850, there have been eight different sets of regulations issued, but as there was no complete satisfaction with any of the rules, and in order if possible to come to a final decision, the various railway managements comprising the Union undertook the carrying out of a series of observations to ascertain the influence of different amounts of super-elevation and gauge slackening on (*a*) the relative wear of the two rails, (*b*) the train resistance, (*c*) smoothness and ease of running, (*d*) cost of maintenance.

The reports sent in are given in detail in the Paper, the general conclusions drawn from them being, that as regards slackening of the gauge, the greatest amounts were the most favourable to a small train resistance, smooth running and low charges for maintenance; while as to super-elevation the amount adopted seemed to have no influence on any of the four points to which the attention had been directed. However, as there is no doubt that a curved track is less favourable to the permanent way than a perfectly straight road, the Technical Committee of the Union has resolved to institute a new series of experiments, with a view to elucidating wherein these unfavourable conditions consist.

W. B.

The Wear of Steel Rails. J. W. POST.

(Organ für die Fortschritte des Eisenbahnwesens, 1899, p. 268.)

The Author has made observations of the wear due to traffic and corrosion of certain rails, whose physical and chemical properties he gives, together with the details of the permanent-way construction. From the tabular statements in the Paper the following general conclusions are drawn:—

(1) The loss of weight was about the same for the rails on single and double-line tracks. (2) The loss of weight for the first 30,000 trains was 28½ per cent. greater for the soft than for the hard rails.

(3) The wear due to the next 65,000 trains was greater for the hard than the soft rails by 9½ per cent. (4) The loss of weight after the first 95,000 trains had passed over was only 5½ per cent. greater for the soft than for the hard rails. (5) The wear per 10,000 trains during the first period of observation for which the total number of trains amounted to 30,000 was, even for the hard rails, greater than during the second period of observation, which was measured by the passage of 65,000 trains.

Further observations are to be made.

W. B.

Deflection of Permanent Way under Traffic. A. WASIUTYNSKI.

(Organ für die Fortschritte des Eisenbahnwesens, 1899, p. 293.)

Observations were made on the Warsaw and Vienna Railway of the deflections of the rails and sleepers under the weight of locomotives and also of the movements that took place at varying depths of the sub-soil. The Paper gives a description of the methods employed in taking the observations, the results being elucidated by diagrams and Tables. As regards the sinking of the earthwork under the permanent way, it was found that an embankment of good material, after 60 years of traffic, was still subjected to movement from a passing train, at depths of 24 feet below rail-level, and at distances from the centre line of 16 feet. This sinking of the material of the embankment amounted at formation level in one case (1 foot 9 inches under the bottom of the sleeper), to from a third to a fourth the depression of the sleeper, and diminished downwards from this point. The sinkings of the sleeper, in the middle under the rails and at the outer ends, were to one another as 69 : 100 : 124 for heavy rails, and as 91 : 100 : 78 for lighter rails. The depression of the sleepers varies uniformly from the centre of a rail length towards the ends, depending on the nature of the ballast, the spacing of the sleepers and the weight of the rail. The slightest want of uniformity in the packing of the sleepers, or an insignificant looking inequality in the rail surface, in fact, the efficiency or otherwise of the plate-laying, had a great influence on the deflection of the sleepers. The depression of the rails and sleepers takes place in advance of the leading axle from 6 feet to 8 feet. The sinking of a sleeper and of the rail over it were not in general the same; with new sleepers, and immediately after the rails had been spiked down, the difference was less without than with a sole-plate.

W. B.

The Oil-gas Works at Hütteldorf-Hacking. FRANZ GROBBEN.

(Zeitschrift des Oesterreichischen Ingenieur- und Architekten-Vereines, 1899, p. 262.)

These works were erected for the supply of oil-gas for lighting the carriages running on the Vienna Stadt Railway and the Western Railway, &c., the works at the Vienna, Westbahn Station, being scarcely able to supply the demands of the Western Railway, and their extension is impracticable for want of available space. The new works in question were therefore erected at the Hütteldorf-Hacking Station, where there was a suitable site.

The building occupies an area of 945 square yards, a main structure containing the boiler-house and the retort-chamber, and two symmetrical wings containing the compressing-pumps and scrubbers, washers, &c. Near the building is the gas-holder, with a content of 17,658 cubic feet. The site being recently made-ground, the foundations, especially of the machinery, required care in construction.

For filling the carriages at the Westbahn Station, there are two cylindrical reservoirs, supplied from the works by a main $3\frac{2}{3}$ miles long. The pressure in these reservoirs varies from 9·5 to 10 atmospheres. For filling the carriage-drums at Hütteldorf there is a network of pipes $1\frac{1}{2}$ miles long.

In the boiler-house are two boilers, each 15 feet 9 inches long, and with 323 square feet of heating-surface of Siemens-Martin steel, and Mannesmann tubes with a working-pressure of seven atmospheres, and a content of 233 cubic feet. In the retort room are two groups of ovens. The first comprises two double ovens, with four upper and four lower retorts. The second group comprises a double oven with two upper and two lower retorts, and two single ovens, with each an upper and a lower retort. The retorts are of cast iron, of $10\frac{1}{4}$ inches in diameter.

In a single oven (with double retort) (8,830 cubic feet,) and in a double oven (two double retorts) 17,660 cubic feet of oil-gas are evolved in twenty-four hours, so that 42,384 cubic feet can be produced at these works per twenty-four hours. The washers, scrubbers, purifiers, &c., are described, and the compressing-pumps. The gas is compressed to 10 atmospheres in the reservoirs, which at Hütteldorf are each 33 feet long, and 3 feet 9 inches in diameter. The maximum pressure of the gas in the carriage-drums is limited to 6 atmospheres. The transport reservoirs for conveying the gas to distant stations, such as Salzburg, are filled to a pressure of 10 atmospheres, and have a content of 7,945 cubic feet.

D. G.

Rail-Sawing and Drilling Car.

(Engineering News, New York, 7 December, 1899, p. 365.)

The high cost of steel rails, and the small wear they sustain before wear and tear at the joints and bolt-holes causes them to be unfit for further use, makes it desirable to use again for branch lines rails that are no longer fit for trunk lines. The car described is fitted with appliances for sawing, drilling, and straightening rails. A freight car, loaded with old rails, is brought alongside. The rails are transferred by cranes and cut, drilled, and straightened in rotation, being finally delivered to another freight car on the opposite side. The saw-cut is usually mid-way between the first and second bolt-holes; but if the damage extends beyond the first, the cut is made between the second and third. The cost of handling and sawing 6,500 tons of 61 lbs. rails was £1,050, or 3*s.* 3*d.* per ton, while the scrap price realized for the ends was £772. In the first machine used, only a single drill was fitted, necessitating the turning of the rail end for end during the process, and throwing the drilling capacity behind the sawing. The car described is, however, fitted with two double or treble-spindle drilling machines, placed 34 feet apart, so that both ends of the rail can be operated upon simultaneously, the drilling and sawing capacities being equal. All the rails to be so dealt with are collected at a central point on each division, special runways being constructed to facilitate loading and unloading.

A. P. H

Trial of a Spark-arrester. C. Cario.

(Mittheilungen aus der Praxis des Dampfkessel- und Dampfmaschinen-Betriebes, 1900, p. 7.)

The Wolf spark-arrester consists simply of a saucer-shaped plate placed in the smoke-box with its edge a few inches below the bottom of the chimney. During the trials the spark-arrester could be instantaneously lowered to the bottom of the smoke-box, thus putting it out of action. The sparks issuing from the chimney of a locomotive are divided into three classes: (*a*) dangerous sparks, which are heavy, continue to burn for some time and which can set fire to straw; (*b*) less heavy sparks, which cannot set fire to straw, but which can singe a hole in a sheet of paper; (*c*) light sparks, which do not fall to the ground and are extinguished at a short distance from the chimney, and which are incapable of burning any other material.

Trials were made with various fuels, coal, brickets, peat, sawdust, and straw. The effect of the spark-arrester was most apparent when the heavier sparks (*a*) and (*b*) were being emitted

from the chimney, the spark-arrester being placed in position completely arrested the dangerous sparks. The number of light sparks (c) was greatly reduced by the use of the arrester, but were not entirely got rid of. A. S.

The Main Line Electric Railway between Burgdorf and Thun. E. THOMANN.

(Schweizerische Bauzeitung, vol. xxxv., 1900, pp. 1 *et seq.*)

This is a description of the electric railway between Burgdorf and Thun, which was opened in July 1899. The length of the line is 25 miles, while the existing railway by way of Burgdorf to Thun *via* Berne is 33½ miles long. The Author gives a history of the scheme, from which it appears that in November 1896, a company was formed, and the estimated cost of construction was £153,120, if steam locomotives were used, but a much better service could be obtained with electric trains for a total cost of £212,000, and the latter system was chosen. The line rises gradually, 767 feet from Burgdorf to Gross-Höchstetten, and then descends again to Thun. There are several tunnels and a number of bridges. The maximum gradient is 25 per 1000, and the gauge is 4 feet 8½ inches. The rails weigh 72 lbs. per yard. The speed of the trains is 22·3 miles per hour, and their weight 50 tons. Three-phase current was chosen with transformers, and three-phase motors upon the engines.

It was considered that the double overhead wires necessary in the case of the three-phase system would be more unsightly than the single wire used for direct current, but it has not proved so in practice. The motors rotate always, at a constant speed proportional to the constant speed of the generator. The Author then enters into a discussion concerning the relative merits of the direct and three-phase motors. Doubts had been raised as to the starting-power of such motors, but no difficulty has arisen; it is, however, essential that the voltage should not fall much below the normal. A pressure of 500 volts was first decided upon for the line, but afterwards powers were obtained to use 750 volts as on the Engelbergbahn, and it is possible that even higher pressures may soon be adopted. The primary supply is at 16,000 volts.

Water-power is obtained from a fall 207 feet high, on the River Kander, and six units of 900 HP. each are installed, each consisting of a horizontal-axis turbine by Escher Wyss & Co., and a three-phase dynamo by Brown, Boveri & Co. Current is produced at 4,000 volts, with a frequency of 40 alternations per second, and then transformed up to 16,000 volts. Details of the overhead-line construction are given; it consists of bare copper wires carried upon insulators fixed to iron poles. Bow contact-makers are used

upon the cars, and the overhead wires are carried zigzag in order to cause even wear upon the whole width of the bow. A special type of points for the line wires has been designed by Brown, Boveri & Co., for the two-wire system, and appears to give satisfaction.

Each car has seats for 66 persons, and is provided with four motors, each of 60 HP. The speed reached is 22·3 miles per hour. The total weight without passengers is 32 tons. Besides these cars, which are known as automobiles, there are also locomotives provided with two motors of 150 HP. each.[1]

E. R. D.

New Compound Express Locomotives for the South Eastern Railway of Switzerland.

(Schweizerische Bauzeitung, vol. xxxiv., 1899, p. 255.)

The Board of the Swiss North Eastern Railway desired to obtain thirty new locomotives, partly to replace old rolling stock and partly to increase the traffic. Ten of these were to be goods engines and twenty passenger engines, and the latter were to be of a new design, as the existing engines were unable to cope with the increasing weight of the trains upon the heavy gradients. It was decided therefore that the passenger locomotives should have compound inside cylinders and four-coupled wheels with a front four-wheeled bogie; that the weight loaded should be about 50 tons, and the weight upon the coupled wheels about 30 tons.

The crank axles were made of Krupp's nickel steel; both cylinders are cast together. A description is given of the general construction of the engines and a series of indicator cards is reproduced. The principal dimensions are given in tabular form, from which the following figures are extracted.

The engines were built by the Swiss Locomotive and Machine Works, Winterthur, and the cylinders were cast by Sulzer Bros., of the same place.

The high-pressure cylinder is 18·1 inch diameter, the low-pressure, 26·8 inch diameter; the stroke, 26 inches; boiler pressure, 196 lbs. per square inch; grate area, 23·5 square feet; total heating surface, 1217 square feet; the firebox is of copper, and the coupled wheels, 6 feet diameter.

The weight of the locomotive empty is 44·6 tons, and loaded 50 tons; the tender loaded is 29 tons. These engines and the express trains will take a load of 350 tons up a gradient of 1 in 200 from April to October, and a load of 330 tons up the same gradient from November to March.

E. R. D.

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[1] *Post*, p. 438.

Mechanical Traction on Tramways and Roads.

S. PÉRISSÉ and R. GODFERNAUX.

(Mémoires de la Société des Ingénieurs Civils de France, 1899, pp. 766–841, and 1900, pp. 1–76.)

Basing their opinions on the experience obtained in France, and mainly in Paris, the Authors consider that, while the public demand in large towns a frequent and quick service of vehicles, profitable working by mechanical traction requires their frequency and capacity to be so proportioned that two-fifths, or at least a third, of the seats shall always be occupied when running. The number of seats per vehicle should not exceed thirty to thirty-five, in order that the car-body may be kept light enough, apart from the weight of the driving apparatus, which depends upon the kind of traction employed. Every vehicle ought to have entrance and exit separate and convenient; the floor should be not too high, and the steps as low and easy as possible. For shortening the stoppages to 25 or 30 seconds, roof seats should be abolished, as well as all attempts at correspondence with other routes; there should be fixed places for stopping at, as near together as the traffic may require; and there should be no stopping between, because neither speed nor punctuality can be attained so long as public convenience is confounded with individual wishes. The expenditure of power per car-mile will always be liable to be increased by stopping and slowing in crowded streets. To attain an average speed of 12 kilometres (7½ miles) an hour, which seems a reasonable limit in large towns, the starting must not take more than 10 to 15 seconds, which means powerful motors and ample adhesion. In this respect electric traction is advantageous, whether with overhead wires, or preferably with conductors underground or on the level of the road; the generating dynamos, particularly when actuated by accumulators, get up the speed quickly, without requiring any of the heavy bulky mechanism used for furnishing extra starting power in other modes of traction. A self-propelling car, in contradistinction to a locomotive drawing one or more carriages, seems specially suitable for town service, on account of its economy due to reduction of dead weight in comparison with live load; and it has adhesion enough, because it can utilize the whole of its own weight and that of the passengers. In towns the road surface is so much affected by the state of the atmosphere, that a road motor-car, which under favourable conditions can draw several other vehicles up a gradient of 1 in 20, can at another time barely propel itself up the same rise. Only exceptionally, on lines of heavy traffic, should bogie cars be employed with fifty seats inside and none outside. Self-propelling cars must not annoy either their passengers or the public in the streets by escape of smoke or steam, or by noise or smell; they must run easily round curves as sharp as 15 metres (50 feet) radius, maintain an average speed of 12 kilometres (7½ miles) an hour including stops, and

take another car behind up 1 in 20. They should be alike at both ends, so as to avoid turning round for the return journey. In contradistinction to self-propelling cars, trains drawn by a locomotive are suitable beyond the confines of towns; or between two neighbouring towns where there are not many passengers to take up or set down by the way; or for suburban week-day morning and evening traffic.

In support of the opinions here summarised, the Authors deal with their subject in detail and at great length. Under the head of vehicles on rails, they treat of the steam tramways worked in France by locomotives of various kinds, including those of Rowan, Serpollet, and Purrey; electric traction with different kinds of motors, speed-reducing gear, suspension of motors, trucks, springs, wheels, car-bodies; accumulators, modes of charging, capacity, duty; interchangeable batteries, charging stations; fireless locomotives working with superheated water; compressed-air motors, air-compressing stations, charging pipes, pressure-reducing valves; gas engines; electric conductors overhead, on the ground, or underground, with continuous or polyphase currents; rope tramways; electric traction with conductors and accumulators in combination; ascent of steep inclines by electric cars with ordinary adhesion, by endless ropes, and by rack rails; cost of traction on different plans of tramways worked by mechanical power. Under the head of road vehicles, the Authors enumerate a large number of public services already running in France, with a few in other countries, and describe the principal vehicles employed; they also discuss the several elements of cost, including first cost, redemption and interest of capital, maintenance and repairs, consumption, and general expenses.

A. B.

Proposed Railway Improvements in Stockholm.

Captain H. Lembke.

(Ingeniøren, Copenhagen, September 1899, pp. 251–3.)

The present Central Station, lying nearly north and south, is a through station, receiving at one end the traffic from the main lines north of Stockholm, and at the other from those south of the metropolis, all of standard 4 feet 8½ inches gauge. Adjoining the northern end is one goods station, and some distance down the southern main line is another; between the two the goods traffic has to pass through the central station. All three stations are too cramped for room, and too confined for shunting; the latter has often to be done across a street crowded with traffic, which is thereby continually blocked. Proposals having been invited for improvements, the best of those sent in is described, and illustrated by three plans showing the existing arrangements and the contemplated alterations.

The new station is proposed to occupy the site of the present with additional ground; and to be a high-level terminus, closed at the southern end, and receiving at the northern the whole of the traffic from the southern as well as from the northern lines. The length under cover will be 180 metres (590 feet), roofed over in three spans of 20, 52, and 20 metres (66, 170, and 66 feet). There will be ten lines of way with platforms between each; eight of them are for arrival and departure by the four main lines, and two are in reserve. The alternate platforms are for luggage; those for passengers are 7 metres (23 feet) wide. The level of the rails will be 4 to 5 metres (13 to 16 feet) above that of the streets they cross over, and the luggage will be raised and lowered by lifts. Departure cabs will set down under cover in an ample yard at the south front, to which some of the principal streets converge. Here will be a large entrance-hall, with booking-offices at the sides and luggage and cloak-rooms in front; two broad flights of steps lead up hence to the platforms, and two others to the waiting and refreshment rooms. Arrival cabs stand in an ample covered yard, which lies alongside the eastern or arrival side of the station, and is reached from the arrival platforms by descending steps, and by passing under the Saltsjö line; the latter runs south-east from Stockholm, and will be brought up over the bridge across the harbour on a rising gradient from its present low-level terminus. For passengers without luggage there will be various other ways out from the central station.

The present northern goods yard is proposed to be retained, adjoining the northern end of the new passenger station, and to be used for fast goods, milk, and piece goods generally; it will be widened, and a goods warehouse will be built 70 metres (230 feet) wide, with separate up and down lines. An extensive range of sidings will be laid out at the present Tomteboda station, alongside the northern main line, just before the Vesterås branch curves off to the west from the main line going north to Upsala and Trondhjem. These new sidings will be at a lower level than the passenger lines, and will be about as far from the central station as is the present southern goods station. The latter also will be enlarged like the northern; and extensive new goods sidings will be laid down at Elfsjö, a station still farther south. Midway between the central station and Tomteboda, a branch with double junction curves will turn off west to a station on the adjacent island Kungsholm; beyond which it will bifurcate into the Mälar and Essingen branches, the latter curving round southwards to join the present southern main line at Elfsjö. This branch will cross the arm of the Mälar lake on a high-level bridge, affording adequate headway for the navigation; over it will run the through goods traffic for stations beyond Stockholm. From Kungsholm high-level station a branch will connect with a low-level cross line, which accommodates several factories, and will fall in with the lines that are proposed to run along the northern and southern strands of the island.

From the present north-eastern branch to Värtan coal harbour,

a new line will turn off southwards through a tunnel to a large station for goods coming in whole truck-loads. This will also form the terminus of the Djursholm and Rimbo line running northwards, of 3 feet gauge; and of the electric tramway running south into the city.

The ground on which the new works will have to be carried out is mainly primitive rock, cropping up to the surface, and in various places 200 feet thick. In the higher ground, boulder sand has been met with in tunnelling.

A. B.

The Regulation of the Great Lakes.

(Engineering News, New York, 4 January, 1900, p. 11.)

A report has been made by G. Y. Wisner, a member of a board appointed by request of the Secretary of War. To keep the level of a lake constant, arrangements must be made to keep the discharge at all times equal to the difference between supply and evaporation. Two projects were considered by the committee. The first was to build a dam with suitable sluices across the River Niagara, at a distance of 12 miles from Lake Erie. This method would, however, involve the expenditure of about £600,000 in purchase of land, which would be flooded, besides miles of dykes for keeping in water at a higher level than the surrounding country. The total cost was estimated at £2,400,000, and even this would not secure perfect regulation of the lakes. The second project was to construct a regulating weir at the foot of Lake Erie. This was to be submerged and fitted with suitable sluice-doors. When supply was at a minimum, the lake was to discharge over the weir, whilst the submerged doors being simultaneously open would allow a wide range of supply consistent with regulation. It is calculated that the minimum recorded discharge from Lake Erie was in 1895, when it was 178,000 cubic feet per second, whilst the maximum, in 1876, was 299,000. The average maximum, however, is 271,000, the higher figure being quite exceptional, and accumulating over some months. It could thus be foreseen and checked by opening the sluices beforehand. The total cost of the project is estimated at £164,000, and time of completion at 2 years.

Experiments made at Cornell University give various values for C in the formula—

$$Q = C.L.H^{\frac{3}{2}}$$

for quantity flowing per second,
where Q = quantity.
C = constant.
L = length of rectangular hole.
H = depth from surface of water to centre of gravity of hole.
The variable in these experiments is depth of submergence.

A. P. H.

The Maintenance of River-beds by Piling. A. SCHLINDER.

(Schweizerische Bauzeitung, vol. xxxv., 1900, p. 4 *et seq.*)

The Author lays down the principle that a flat ellipse is the best form of cross-section for the bed of a water-course, and believes the best system of maintaining the form to be a special method of piling. The method referred to was first adopted in 1869 and 1870 for the Wildbach district of the Canton Glarus in Switzerland, but it found no further use until the River Ergolz, near Liestal, was treated experimentally in 1889. Since that date it has been widely adopted in the district. About 12 years ago a project for the regulation of the course of the Weichsel, which cost £80,000, was based upon this system. The method has also been adopted for the correction of the River Töss in the Zürich canton at a cost of £20,000. The municipality of Basle then placed the correction of the Wies in the hands of the Author, and he dealt with a portion 0·31 mile long, where the banks and bottom were always being washed away. The Author then explains his system in detail. A trench is first cut across the bed of the river, this trench being about 30 inches to 35 inches deep on the up-stream side, and tapering to zero on the down-stream face; tree-trunks are then laid with fascine-work in the trench, and the whole is bound to short vertical piles, and the trench is then filled up. The result is that the action of the current deposits material on the down-stream side of such a dam, and cannot wash it away owing to the slant of the fascine-work being in the direction of flow of current. Illustrations are given of the precise method adopted in the River Wies; the former trapezoidal channel was altered to an elliptical form, and the dams were placed from 80 feet to 110 feet apart. The banks were finally protected with turf, and this was found satisfactory.

The Author gives the cost per "girdle," or submerged weir, at about £32, and if forty-five such dams were put in per mile the total cost would be about 17*s.* 6*d.* per yard run of stream.

E. R. D.

The Canal from Lake Thun to Interlaken. F. ALLEMANN.

(Schweizerische Bauzeitung, vol. xxxiv., 1899, pp. 98 *et seq.*)

One of the most important improvements in transport of recent years in the Bernese Oberland has been effected by the construction of the ship-canal from the Lake of Thun, by which vessels are enabled to pass from that lake to the west end of Interlaken, while they can reach the east end of the town by means of the upper navigable portion of the River Aare from the Brienzersee. There were rival projects for a railway and a canal. The water-

level of the Brienzersee is 19·7 feet above that of the Thunersee, and the two lakes are 3·72 miles apart, and at Interlaken there is a dam and the water is used to actuate mills. The gradient of the River Aare between the Brienzersee and Unterseen is very small, and the river divides into two parts, in each of which is a lock, and the fall of about 5·74 feet to 6·56 feet is used for producing power. Between Interlaken and the Lake of Thun the course of the Aare was very crooked and filled with sandbanks. It was decided that it was impracticable to canalize the Aare itself, owing to the difference in levels between the Thunersee and Interlaken, and, moreover, it would have been impossible to make special navigation charges, as there was a public right of way. The final scheme adopted, therefore, consisted of rendering the course of the river itself much straighter, and constructing an independent canal with a water-level throughout the same as that of the Thunersee, so that at Interlaken the level in the ship-canal is 9·84 feet to 11·5 feet below that of the River Aare. The Shipping Company obtained the concession for carrying out the combined works with sole right to use the canal, but with the obligation of keeping the canalized River Aare in proper order.

A description of the new course of the river is then given with sections of the water-way and levels, the gradient is 1·7 per 1,000, and the bed was made of such a width as to obtain a bottom velocity of 2·6 feet to 2·95 feet per second. At intervals piling is fixed in the bed to prevent the erosion of the bottom.

An attempt was made to produce the cutting by excavating a canal 98 feet wide and relying upon the current to widen it to 120 feet, but it was a failure; training walls were built out into the Thunersee.

The total cost of the works did not exceed the estimate of £18,400 for one year.

Various illustrations show details of the cross sections of the canal.

The total cost, exclusive of the administration buildings, was £71,624.

At Interlaken the overflow of the River Aare is used to actuate turbines which drive dynamos and light the town, and the tail-water is carried into the ship-canal and keeps up a constant current in it from Interlaken to the Thunersee.

The cost of the power-house, plant, etc., was about £14,600.

E. R. D.

Report of the Alsatian Association of Boiler Owners.

(Bulletin de la Société Industrielle de Mulhouse, 1900, p. 55.)

Mr. Walther Meunier, chief engineer of the Alsatian Boiler Owners' Association, gives details of the various boilers supervised by his Society. They have 2,624 on their books, and nearly 7,000

inspections were made during 1899; 106 boilers were tested by hydraulic pressure, and forty-nine calorimetric tests of the fuel used in these boilers were carried out; 589 steam engines were tested, and indicator diagrams taken in each case. Interesting and complete details of trials of boilers and steam engines are given, made under ordinary working conditions, and with comparatively old boilers. Ninety-one experiments were also carried out to test the evaporative power of various coals burnt under boilers of numerous types; Cornish, Lancashire, Thomas-Laurens, Babcock, Belleville, de Naeyer, etc.; these are summarised in a Table. A summary is also given of seventy calorimetric tests made on thirty-one different kinds of coal. Of these, five were French, fourteen German, six English and Scotch, and six Belgian. The heating value of the raw fuel varied from a minimum of 4,112 calories per gramme = 7,401 B.T.U. per lb., for French peat, to a maximum of 8,046 calories per gramme = 14,482 B.T.U. per lb. for Belgian briquettes. The percentage of ash was from 19·7 per cent. in German small coal from Lorraine, to 4·8 per cent. English coal seems from this Table to be of fairly average composition and heating value. The Demoulin apparatus for purifying feed-water from mud and lime, by drawing it through a special kind of filter, was applied to three boilers, and tested. A new water-gauge by Mr. Hafner is also mentioned.

The dearth of coal is given as a reason for the careful calorimetric tests which accompany the Report. By such means an endeavour is made to determine which is the cheapest coal, that is, the coal having the highest heating value and smallest percentage of ash.

B. D.

Steam-engines in Prussia, 1879–99.

(Mittheilungen aus der Praxis des Dampfkessel- und Dampfmaschinen-Betriebes, 1899, p. 584.)

The Royal Prussian Statistical Office have published particulars of the steam engines in Prussia up to 1st April, 1899, showing a total of 91,187 steam engines having an aggregate of 3,717,264 HP. The Paper gives the corresponding figures from the year 1879 showing a steady growth in the number of steam engines, and in the average power of each steam engine. In 1879 the average HP. was 27, in 1899 the average HP. was 41.

A. S.

Fifty-ton Electrical Travelling-Crane.

(Zeitschrift des Vereines deutscher Ingenieure, 1899, p. 414.)

The illustrations accompanying this Paper fully explain the construction of this crane, which is employed at the Romback Ironworks to raise ladles of molten metal, weighing 15 to 20 tons,

and to empty them into the converters. The span of the main traveller is 7 metres (22·96 feet). The upper traveller carrying the hoisting gear has a lateral motion each way of 1 metre (3·28 feet). The height of lift is 16 metres (52½ feet). A separate motor regulates each operation, one of 70 HP. and 620 revolutions drives the winches for the two square linked chains, which are 1,490 millimetres (58·66 inches) apart; special provision is made for suspending the slack. A magneto-electric, and a self-acting brake[1] are provided. The hoisting gear is mounted on the transverse traveller; from its extremities four built iron frames, well tied and braced together, are suspended; these serve as guides for the box girder which carries the sheaves for the hoisting-chain, and for the suspending-rods connected with it. The trunnions of the ladle also rise between these frames; all lateral motion of any description is thus provided against. An 18-HP. motor drives the main traveller, a 5-HP. motor the upper one, and a 12-HP. motor the tipping chain. All the switch handles regulating the above are within easy reach of the driver, who occupies a platform suspended from the main traveller at a height of 2 feet from the floor.

W. A. B.

Gas-engines for Electro-motors. M. Krone.

(Zeitschrift des Vereines deutscher Ingenieure, 1900, p. 39.)

In this Paper the Author sets forth the economic advantages of the employment of gas-engines to generate electrical power. Omitting factors common to all, detailed estimates of the buildings, plant, and working-expenses of four different systems are given, each designed to supply a moderate-sized town with electrical light and power to the extent of 4,000 glow-lamps of 16 candle-power, or their equivalent, and 100 HP. for motors. The first system is worked with steam-engines without condensation, the second with condensation, the third with ordinary illuminating gas, and the fourth with Körting's gas-plant. Illuminating-gas compared with steam of both descriptions shows an annual saving in each case of £305 and £440 respectively; Körting's gas, similarly, economies of £266 and £401, the cost of coal being reckoned at 18*s.* per ton. The Author also gives full details of the Clausthal Tellerfeld Electrical Works, with Körting's gas-plant, which provide for a population of 13,500 and supply 3,500 glow-lamps of 16 candle-power, 155 of 25 candle-power, and 50 HP. for electro-motors.

A tabular statement of the monthly consumption of coal and the power generated shows an average of 707 watt hours per kilo of coal.

W. A. B.

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[1] Zeitschrift des Vereines deutscher Ingenieure, 1899, p. 1485.

Gearing for the Transmission of Electrical Power.

(Zeitschrift des Vereines deutscher Ingenieure, 1899, pp. 1417, 1487, 1528, 1563.)

The defective construction of the connections between machinery and the motors driving it is frequently the cause of the unsatisfactory results commonly complained of. This Paper is written for the purpose of pointing out the ordinary defects, of demonstrating the principles involved, and of recording the results of a series of observations conducted by the Allgemeine Elektricitäts Company.

The Author deals with the subject theoretically and practically under the following heads:—(1) Theoretical construction of teeth; (2) friction; (3) wear; (4) duration of engagement; (5) actual and characteristic wear; (6) conclusions from characteristic wear; (7) construction of teeth as regards wear; (8) construction of teeth as regards resistance; (9) manufacture of cutters and teeth; (10) result of errors in division and form of teeth; (11) construction of wheels; (12) construction of gearing and bearings, etc.; (13) results of observations; (14) description of machines subject to observation.

The Author in his somewhat lengthy article supports the theories enunciated by the experience obtained in practice. The points specially emphasized are extreme exactitude in the cutting of the teeth, and in the arrangement of the bearings. The gearings observed were of the following materials:—Raw hide, phosphor bronze, cast iron and cast steel both rough-cast and tooled; perfect lubrication is essential. The Paper is very completely illustrated with numerous diagrams, drawings, and photographs.

W. A. B.

Self-acting Plugs for Burst Tubes in Water-Tube Boilers.

A. JANET.

(Mémoires de la Société des Ingénieurs Civils de France, 1899, pp. 762–5.)

On the head of a slender stalk, from two to three times as long as the bore of the tubes in a water-tube boiler with nearly horizontal tubes, is a hemispherical plug, about half as large again as the bore. One of these plugs is provided at each end of every tube. When the stalk is inserted into the tube, the plug hangs down outside just clear of the orifice; a horizontal rod prevents the plugs from falling further out of a whole row of tubes. If a tube bursts, the rush of water into it carries the plug along with it, and effectually blocks the orifice. The body of the plug is of iron, steel, or gun-metal, solid with the stalk, and is coated with

a soft layer of lead to form a water-tight joint when pressed against the orifice of the tube by the boiler pressure. In sectional boilers, where the tubes are arranged in separate series, it may suffice to put a plug at each end of every series only, instead of at every tube. The plan has been adopted with success by its author, Mr. Ravier, engineer in the French navy, in a torpedo-boat with Du Temple boiler, in which the bursting of a tube produced no inconvenience at the moment of its occurrence; the boat was able to continue its voyage, and to put to sea again next day without repair, the burst tube being effectually plugged at both ends by these self-acting bungs. They have now been in use eighteen months in various torpedo-boats and tugs, with satisfactory results. The weight and shape of the plugs are so proportioned as to prevent any risk of their accidentally blocking the tube ends in the regular working of the boiler. The arrangement is suitably modified for different kinds of boilers, such as the Oriolle, the Belleville, and boilers with vertical water-tubes.

A. B.

Regulations (Danish) concerning the Arrangement and Working of Lifts and Hoists driven by Machinery.

(Ingeniøren, Copenhagen, September 1899, pp. 263–5.)

While the regulations issued on 13th May 1899 by the Danish Home Office are mainly such as are elsewhere generally recognized already, mention may be made of a few points deserving attention in regard to passenger lifts. The lift cage must be closed in all round, except at the entrance, either with solid sides and roof, or with trellis work having openings not exceeding 1 inch. It must be lit up inside, and must contain a notice of the number of passengers allowed. From any point in its travel there must be the means of signalling if in difficulty. Except where their adoption would be attended with serious inconvenience, entrance doors must be fitted inside the cage itself; these must not open outwards, and must be kept locked while travelling. Where they are dispensed with, at every landing the lift well must be fenced to the full height on the entrance side, with no inward projection; and the clearance between the cage and the well must nowhere exceed 2 inches. In ram lifts, the cage and ram must be securely joined together. A hanging cage must be suspended by at least two ropes or chains, each of which must alone be strong enough to carry ten times the weight of the cage fully loaded. Each must also be connected with either a stopping apparatus or a brake, so arranged that the cage shall either be stopped in a fall of not more than 1 foot, or else shall be let down at a speed not exceeding 3 feet a second. Lifts worked by a winding drum must

be provided with a contrivance for preventing the rope from becoming slack in the event of the cage sticking in its descent, and at the same time for stopping the drum. Every counter-balance weight is likewise to be hung by at least two ropes or chains, each having ten times the strength necessary to carry the weight. The counterbalance weights must be securely guided, and the space in which they work must be carefully fenced, so as to guard against all possible risk of accident. Drawings of intended lifts have to be approved beforehand by the local factory inspector.

A. B.

Consumption of Explosives in the Dortmund Collieries. HEISE.

(Glückauf, vol. xxxv., 1899, p. 697.)

In the Dortmund district the explosives used are of three classes. The first is black powder, of which different kinds are used in which the proportion of nitre varies from 65 per cent. to 75 per cent. The second class comprises the dynamites, of which gelatine-dynamite is the variety mostly used. Of the dynamite used 97 per cent. consists of gelatine-dynamite and only 3 per cent. of kieselguhr-dynamite. Lastly, the third class comprises the safety explosives, the ammonium nitrate explosives and carbonite. During the year 1898 in the collieries of the Dortmund district, there were used 4,033 tons of explosives, consisting of 332 tons of black powder, 2,248 tons of dynamite, and 1,453 tons of safety explosives. The output of coal during the year having been 51,001,551 tons it follows that 184 lbs. of explosives are used for every 1,000 tons raised. The value of the explosives used during the year was £219,180. The cost of the fuse is about 1*d.* per shot. With 13,000,000 shots the cost was £52,000 during the year. The cost of explosives and fuse represents about 1¼*d.* per ton of coal.

B. H. B.

Magnetic Separation of Ores. H. WEDDING.

(Verhandlungen des Vereins zur Beförderung des Gewerbefleisses. Sitzungsbericht, 1899, p. 155.)

The Author describes two machines for sorting ores according to their magnetic properties. In one of these the ore is carried on travelling bands, the magnets being underneath; the other consists of two horizontal electro-magnetic circular cylinders, the upper one of which has a ribbed surface, the lower one being

encased by a non-magnetic substance of a thickness equal to three-fifths the clear space between the metal of the rollers.

The ore is passed through between the rollers as they are rotating in opposite directions, and becomes separated into three different lots which fall on to aprons and into bins underneath and in front of the machine.

The Author discusses the methods of preparing different ores for magnetic treatment, and recommends microscopic examination of prepared sections as a means of determining the required fineness of crushing, and even in cases as a substitute for chemical analysis.

Certain minerals on being roasted undergo a chemical change which renders them capable of separation by magnetism into their simpler constituents.

One means of separating many ores, which in the dry state require the action of strong magnetism, is to place them in still or running water and then apply the magnetic forces, which thus become relatively much more powerful, seeing that the action of gravitation on the minerals is partly suspended. This process, however, is still awaiting the invention of a thoroughly practical apparatus.

The Paper also contains an account of the various means of rendering magnetically separated iron ores—which have of necessity been finely divided—suitable for the blast furnace, by making them into briquettes with clay, lime, silica, coal, tar, pitch, petroleum and cellulose residue, etc.

The Author looks to the time when the improvements in the application of magnetism to the sorting of ores will enable mines that have been abandoned to be reopened and worked at a profit, and he also hopes that manufacturers will be rendered independent of the Siemens-Martin process, and the consequent heavy expense of purchasing scrap-iron, by the adoption of some method of treating powdered ores in the Siemens furnace.

W. B.

The Gillier Pit of the Péronnière Mining Company.

BOUTEILLE.

(Comptes Rendus Mensuels de la Société de l'Industrie Minérale, March, 1900, p. 9.)

This is an account of the sinking of a new pit in the neighbourhood of St. Etienne, which is intended to cut the great seam of Rive de Gier at a depth of about 900 metres (2,953 feet), the diameter of the excavation being 5·1 metres ($16\frac{3}{4}$ feet), and the finished diameter within the brick lining 4·35 metres ($14\frac{1}{2}$ feet). For the first period the ordinary method of hand-sinking by length of 15 metres and subsequent walling in brickworks was

adopted until a depth of 86 metres was reached, when the work was stopped during the erection of the permanent pit-frame and the engine- and boiler-houses, and on the resumption in May, 1889, a new method was adopted which forms the special object of the Paper. This consists in working by short lifts of 3½ metres, each of which is completely walled and fitted with buntons and guides for the cages before the excavation of the next one below is commenced, the same set of men being employed successively in the different operations of sinking, walling, and setting the guides. The sinking was at first done by hand-drilling, but subsequently Burton rock drills have been adopted. These are mounted in groups of three on horizontal bars at the back of a lattice-frame structure 9¼ metres high, weighing 2·6 tons, which is lifted and lowered by the main engine, and when at work is fixed in position by jack-screws at the bottom. The six machines on the two frames have sufficient overhang on their mountings to command the entire surface of the bottom of the shaft from one setting. At the bottom of each length, 3½ metres below that next above, the rock is cut back to form a seat for a ring of concrete about 800 millimetres square in section, moulded upon a suspended ring of sheet iron of the finished diameter of the pit. Rail guides of the Briart form are used; they are carried on joists 4·75 metres long, weighing 43 kilograms per metre, placed 3·5 metres apart, and cemented at the ends into the concrete rings. The walling-in brickwork, 300 millimetres thick, is done from a platform carried by four differential pulley block-tackles, the whole body of sinkers being employed upon the work, which occupies about eleven hours for the height of 2·7 metres between two concrete rings, or thirteen hours when the time for fixing and removing the platform is included.

For raising the rock broken in the sinking, as well as for lowering materials and other accessory operations, sinking-cages of a very special kind are used. These are of narrow rectangular form, 1·6 by 1 metre, and 11 metres high, divided into five compartments ranging in height from 1·6 to 4 metres, three of which have hinged flaps for use as extended platforms. These are specially used in fixing the rail-guides, which are in 7-metre lengths, and are supported at three points. For the permanent cages they are 2·4 metres apart, but an outside series of 3·43 metre gauge is in temporary use for the frames carrying the boring machines, which will subsequently be used for the surface lines.

For ventilation the pit is divided by a brattice of sheet iron fixed between the buntons, the air circulation being kept up by a Mortier fan of 350 cubic feet capacity per second. Lighting is done with acetylene lamps, consuming 240 grams of calcium carbide in the eight-hour shift.

Since the new system was introduced, the rate of progress has been about 20 metres per month, although there have been numerous interruptions due to strikes, fires, and other causes; but

it is expected that when the boring machinery is completely established, about 300 metres per annum will be obtained.

The main winding engines, which are now nearly completed, are of the couple horizontal-cylinder class, with cylinders 1,200 millimetres in diameter and 2,000 millimetres stroke, taking steam at 150 lbs. initial pressure. The cylindrical drum is 8,000 millimetres in diameter and 2,900 millimetres broad. The pit frame is 36 metres high, with guide pulleys 6 metres in diameter. The drawing-ropes of steel wire, 57 millimetres in diameter, weigh 11 kilograms per metre, and have a total tensile strength of 200 tons. The load for 950 metres depth is:—

	Kilograms.
Cage	3,425
Nine tubs empty	2,025
Coal	4,050
	9,500
Rope about 1,000 metres at 11 kilograms	11,000
	20·5 tons.

The speed of winding is to be from 12 to 15 metres per second. Detailed drawings of the different arrangements adopted are given in seven plates accompanying the Paper.

H. B.

Coal-mining in New South Wales. H. F. Bulman.

(Colliery Guardian, vol. lxxix. p. 349.)

The New South Wales coal basin extends from Port Stevens to Clyde River (200 miles), and the greatest breadth on land is about 90 miles, the coal measures extending eastward and under the sea to an unproved distance. There are three separate series, of different geological ages, containing an estimated aggregate thickness of 150 feet of coal.

The most valuable seam is the Borehole seam (6 feet to 22 feet), which is largely worked at Newcastle (Port Hunter) where the depth is about 200 feet. Further south, at Lake Macquarie, the depth is 1,362 feet, and the seam thins out to about 5 feet of poor coal; but there are fifteen overlying seams, 2 feet to 20 feet thick, three of which are worked. Of these, the Great Northern 20 feet seam contains 5 feet to 8 feet of good coal in the centre; the Australian seam is 20 feet thick, but greatly divided, and of little value; the Victoria tunnel yields 5 feet to 6 feet of workable coal;

the Dirty seam, 5 feet of clean coal; the Yard seam, 3 feet thick, cropping out at Newcastle; the Borehole seam.

The amount of available coal in the Newcastle district has been estimated at 950,000,000 tons. South of Sydney the same measures are worked near Bulli and Lake Illawarra; and they crop out in the Blue Mountain district, where several collieries are at work near Lithgow and Eskbank.

Around East Maitland (18 miles north-west of Newcastle) the middle coal measures crop out, and are worked by four or five collieries, raising 5,000 tons to 6,000 tons per annum; and, further north-west, near Greta, is an outcrop of the lower series, containing a seam of 18 feet of good house coal. This series also reappears on the Clyde River at the extreme south of the basin.

The upper coal measures contain beds of oil shale, worked at Lithgow, and again at Joadja, the output being 29,689 tons in 1898. C. S.

The Ignition of Coal-dust by Electricity. S. F. Walker.

(Colliery Guardian, vol. lxxix., p. 161.)

The explosion of coal-dust in mines necessitates a certain combination of predisposing causes, viz., the presence of a cloud of dust and the simultaneous passage of a large body of flame in contact therewith; and in every case there must be a certain minimum quantity of dust, ignited at a certain minimum rate, in order to develop the necessary amount of heat for producing and amplifying an explosion. Now, in the case of a glowing wire or the electric arc, although the temperature of each is very intense, it is localized owing to the small area of generation and to the effects of radiation and convection; and the amount of coal-dust that can be ignited at any given time is therefore very minute in comparison with that fired by the flame of a blown-out shot in blasting. Consequently, neither the electric arc nor a glowing wire can bring about an explosion of coal-dust alone, in the absence of fire-damp. Moreover, the arc lamp is hardly likely to be used in positions where coal-dust is present in large quantities, owing to the low penetrative power of its rays through such an atmosphere; and under such circumstances more light is thrown by a 16- or 32-candle-power glow lamp.

The only possible sources of danger from coal-dust ignition within the mine are glowing filaments of broken glow lamps, sparks from the switches or commutators, and glowing resistance wires; but as Heise and Theim have shown the great difficulty with which these give rise to explosions, even in presence of fire-

damp mixtures, the risk of coal-dust explosions caused by any form of electrical apparatus used in coal mines appears to be absolutely non-existent.

C. S.

Gas and Petroleum Borings in China.

(Ingeniøren, Copenhagen, September 1899, pp. 269–271.)

These occur in the large western province of Se-Tchaon (otherwise Sze-Chuen), which borders on Thibet. The region in which they are situated is identified by the Author as being intersected by a small river, on the left bank of which is Fon-choen and on the right the town of Ouan-hien; and it is reached by passing through the town and fertile neighbourhood of Lony-kiang. The principal petroleum district occupies only about 300 square kilometres (120 square miles). The largest spring of natural gas, which is also one of the oldest, is close to the Tse-lion-tsin mountain range, and is known by the same name. A vast tract of yellow sand and limestone is dotted over with scaffolds or "derricks," and the roar is heard of escaping gas; the atmosphere is saturated with salt, sulphuretted hydrogen, and various other gases. The region is volcanic, and within historical times has twice been visited with eruptions; this accounts for the surface irregularities, and for the different depths of wells sunk close together. Some of the wells yield only brine, others only petroleum, and others only natural gas; some also yield both brine and petroleum, and a few brine and gas. Most of the brine is found at a depth of from 930 to 1,000 metres (3,050 to 3,280 feet), and these wells are the most productive of petroleum gas. The boring tool is of the free-falling kind; a hard-wood rod or lifter, with an iron cap at each end, serves as a hammer or monkey, sliding through the top of an iron link, and falling upon the chisel or bit attached to the bottom of the link. Its primitive construction implies an enormous expenditure of time and labour to produce even small results; yet a bore-hole has by this means been put down to a depth of even 1,100 metres (3,600 feet). Four qualities of petroleum are drawn up from the wells:—the first is of very light colour, and is used in its natural state for burning with refined petroleum in special lamps, and also for curing skin diseases, rheumatism, and other ailments; the second is green, and of less value; the third is yellow; the fourth is black, thick, and sticky. The temperature of the petroleum and brine as they come from the wells is about 250° C. (*sic*),[1] while that of the atmosphere is about 40° C. or 100° F. The natural gas is of two kinds: that which comes from a depth of 75 to 150 metres (250 to 500 feet) gives a white flame, and is found in small quantities only; that which comes from 670 metres

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[1] Query misprint for 50° C., equivalent to 120° F.—A.B.

(2,200 feet) depth issues in large volume at high pressure, and contains much hydrogen with particles of silver, and burns with a blue flame, producing a high temperature. The shallower wells are much affected by the state of the atmosphere: in fine weather without wind the flow of gas is considerable; under the contrary conditions the volume is much less, and it occasionally happens that scarcely any gas can be obtained. There are only about forty gas wells in operation. Many of them often catch fire, usually with the accompaniment of explosions, producing a sea of flame, 100 to 120 feet round and 60 to 70 feet high; one such fire has burnt for a year without the natives being able to put it out. The gas is used for evaporating brine, lighting factories, and as fuel. The various appliances are described by the Author, and are all of a primitive and wasteful kind.

A. B.

Electrical Launches.

(Zeitschrift des Vereins Deutscher Ingenieure, 1899, p. 1456.)

The employment of electrical launches, though limited to trips of comparatively short duration, according to the capacity of the accumulator-battery, offers many advantages, especially where a boat is required which can start at a moment's notice, and where its services are intermittent, such, for instance, as police and Custom-House boats, tenders to men-of-war, ferry, and pleasure-boats. The machinery occupies little space, while during intervals of rest there is no waste.

The Author in this paper discusses the nature, construction, and arrangement of the accumulator-battery, the motors, and regulating appliances of the most approved launches in Germany. Tables and diagrams of their performances are also given. Among them, some built for the Berlin Industrial Exhibition of 1896. Dimensions: length, 49 feet; beam, 8·85 feet; draught, 3·28 feet; freight, 60 passengers; 18-HP. motor, making 500 revolutions, and battery of 80 elements, with a capacity of 500 amp-hours; weight of electrical plant and machinery, 7 tons. Also a large steel freight-boat of 67 tons: length, 65·6 feet; beam, 13 feet; draught, 5 feet; motor, 20 HP.; battery, 45 elements. With a single charge this vessel makes a five-hour trip at a speed of 6·83 miles. The use of electrical power effects a great saving in the cost of propulsion, and in other expenses. The Paper is supplied with thirty-three illustrations.

W. A. B.

The Foundations of the New Croton Dam.

C. S. Gowen, M. Am. Soc. C.E.

(Proceedings of the American Society of Civil Engineers, 1900, p. 2.)

The construction of this dam[1] on the Cornell site was begun in 1892 and is now two-thirds completed. The chief engineer is Mr. A. Fteley.

The extreme height of the dam from the lowest foundation to the crest is 260 feet, the maximum thickness being 190 feet. The final location of the site was the result of an examination of an extensive series of diamond-drill borings, 2 inches in diameter, carried down to the hard rock, which was found to consist of blue limestone. The borings indicated the presence of more or less open seams in the limestone, and the occasional occurrence of a sudden loss of the water supplied to wash out the drill-holes showed that these communicated with free outlets.

Three cableways were erected across the valley on the line of the dam so as to command the whole width of the foundations, and these were supplemented by railway inclines. The slopes of the excavation varied from 1½ horizontal to 1 vertical in sand and gravel, to ½ horizontal to 1 vertical in hard pan. The limestone varied greatly in character; in places it was sufficiently compact and watertight to answer for the foundations of the dam without further preparation, and in other cases it contained belts of loose rock of various widths, through which water freely flowed, in one case opening into a cave; or layers of stones, with the spaces between filled with mud. Numerous holes about 14 feet deep were drilled into the bottom of the trench to search for cavities. In most cases pipes were carried up from the latter, as it was found to be more practicable to grout them under pressure when the opening was weighted with masonry; in case water issued from them a second pipe led to a convenient sump. The cave was built up with rubble masonry, and open seams were filled with small stones and then grouted. In some cases when there was a doubt as to whether grout could be forced successfully through the pipes, owing to the presence of water, plastic clay was driven into them by means of a small pile-driver with a drop of a few feet. Many pipes and the cavities they were connected with were thus filled.

A. W. B.

Illumination with Water-Gas. Fürer.

(Glückauf, 1899, p. 829.)

The town of Pettau in Styria last year successfully replaced the petroleum lighting previously employed by water-gas light-

[1] Minutes of Proceedings Inst. C.E., vol. cxix. p. 422.

ing. The water-gas was made by Dr. Hugo Strache's process from Schallthal and Buchberg coal mixed with Prussian coal or coke. The installation, including buildings, 7,000 yards of pipes, street-lamps and house-connections, cost £8,500. There are eighty 100 candle-power street-lamps, seventy-four 50 candle-power street-lamps, and about 1,000 private jets. The private jets are of 25, 50, and 100 nominal candle-power. The gas consumption was found to be as follows :—

Burner.	Gas Consumption per Hour.	Illuminating Power.
Candles.	Cubic Feet.	Candles.
25	2·2	26
50	3·2	56
50	4·0	80
100	6·6	100

There are two producers, each designed to supply 1,770 cubic feet per hour. The actual yield is somewhat greater, so that 85,000 cubic feet of gas can be produced daily. Water-gas is supplied to private houses for lighting purposes at 7*s.* per 1,000 cubic feet, so that one 50 candle-power burner costs about a $\frac{1}{4}$*d.* per hour. For heating, cooking, and power purposes it is supplied at half that price.

B. H. B.

Purification and Softening of Water. E. Wehrenfennig.

(Organ für die Fortschritte des Eisenbahnwesens, 1899, p. 214.)

This article deals with the purification and softening of water for railway purposes, and especially describes an arrangement whereby the water can be chemically treated in the ordinary tanks, without special plant and in a continuous manner, so that at no time is any part of the tank space shut off from forming part of the volume of supply.

In the particular plant described there are two tanks. The water before it enters these is automatically divided into three portions by weirs of different widths, the stream over the widest entering a pipe which delivers it into tank No. 1 at a point near the bottom, and the two other portions going to be mixed (automatically) with lime and soda respectively, after which they are pumped up and delivered at the point where the first portion issues into the tank.

The chemical reactions occur at this common meeting point of the impure hard water and the reagents, the lime being precipitated as a simple carbonate, and the magnesium and iron compounds as hydrated oxides.

As the water rises in tank No. 1 it becomes clarified, but is still

further cleared of the precipitates and other impurities by being sent through a filter on its way to tank No. 2.

The Paper describes the whole plant and the chemical changes in detail, and is well illustrated.

W. B.

Condensation of Steam in Blower Systems of Heating.

R. C. CARPENTER.

(Engineering News, New York, 1 February, 1900, p. 72.)

The Author gives the results of experiments made under varying conditions upon the heat taken up by air passing through a heater propelled by an air-blower. The objects of the experiments were to ascertain:—(*a*) The relations between the steam pressure in the heating coils, and the heat absorbed by the air; (*b*) the relations between the heating surface, and the total heat absorbed by the air; (*c*) the effect of varying the velocity of the air; (*d*) the condensation of steam per square foot of heating-surface per hour at various steam pressures; (*e*) the behaviour of the blower under different conditions.

In making these experiments the Author used two anemometers and several Pitot tubes. These instruments showed great disparity of air-velocity in different parts of cross-section of the delivery pipes. The Author gives curves showing the results of his experiments, and draws the following conclusions from them. Increasing the air's velocity increases its capacity for taking up heat at a faster rate than the square root of the increase in velocity. An increase in steam-pressure results in a greater absorption of heat by the air, but not in proportion to the increase in steam temperature. The condensation of steam is in proportion to the amount of heating surface. The Author points out that these results cannot be taken as true for other fans working under other conditions. He gives CD^3n as an expression for the delivery of air by a rotating fan, where D = diameter of fan in feet, n = revolutions per minute, and C = a constant depending upon the other conditions.

A. P. H.

Testing Blowing-Fans. R. C. CARPENTER.

(Engineering News, New York, 8 February, 1900, p. 101.)

The object of testing blowing-fans is to determine the volume and pressure of air delivered, and from these quantities the efficiency is found. The power given to the fan can be measured with tolerable accuracy, as also can the pressure of air in the delivery pipe. Observation of the velocity of air completes the

required data, since from this the quantity delivered can be calculated, the area of cross section of the pipe being known. From the velocity, the kinetic energy in the moving mass of air is obtainable, whilst the pressure is a measure of energy stored in potential form. By adding the potential and kinetic energy, the total energy given out by the fan is obtained, and by comparing the known energy absorbed by the fan the net efficiency is arrived at. The crucial point is the correct measurement of the air-velocity, which is usually made with the anemometer, or the Pitot tube.

The Author describes a method of calibrating these instruments by the following method of check measurement. Air at a constant velocity is passed through a tube, and its temperature is raised a fixed amount by a steam coil. The condensed steam from the coil is weighed and the total heat expended in heating the air is thus found. Since the rise in temperature of the air and its specific heat are known, the total weight of the air can be found, and its velocity deduced from the known sectional dimensions of the tube.

The Author gives the chief causes of the inefficiency of fans as due to friction of air against the vanes and casing, and the unresisted expansion of the air as it escapes between them. Some authorities consider the unavoidable losses amount to 25 per cent., the maximum efficiency thus being 75 per cent. The Author states that 50 per cent. efficiency is usual, and urges the advisability of regarding with suspicion any claim for greater efficiency. The chief source of error of measurement is the anemometer, which is likely to get out of order, especially after working some time.

A. P. H.

The Barren Island Garbage-Reduction Works, Greater New York.[1]

(Engineering News, New York, 1 February, 1900.)

The garbage of New York, before being finally disposed of, is treated in large garbage-disposal works, where marketable grease is separated. The plant can deal with 1,000 tons of garbage per day, this being increased to 1,500 tons for short intervals, and in the height of the season. The garbage is loaded on lighters, two of which, carrying 300 tons each, are towed out a distance of 27 miles from New York to Barren Island. The process of treating is one of boiling, pressing, and separating. The garbage is fed from the quay-side on to a conveyor formed of an endless chain, with projecting blades at intervals of about 2 feet. On this it is taken to the digesters, of which there are forty-eight of

[1] Minutes of Proceedings Inst. C.E., vol. cxxx. p. 347.

10 tons capacity each. The digester is a vertical steel cylinder of 5 feet 6 inches diameter, and 14 feet high, the bottom being conical, while the top is dome shaped. Before charging, water is admitted to a depth of 3 feet to 4 feet, and after charging, the charging-door is locked and boiling allowed to continue for 8 hours, under a pressure ranging from 30 lbs. to 80 lbs. After boiling, the garbage is passed on to the presses, of which there are sixteen. They are actuated by screws, and so arranged that the speed of advance decreases as the process continues. The water and grease pressed out of the garbage are led off by a drainage system, and are pumped into settling and cooling tanks, in which they separate one from the other. The pressed garbage is next dried in twelve driers, consisting of steel cylinders 5 feet diameter and 14 feet long. They are jacketed with steam at a pressure of 75 lbs. per square inch, and are provided with a central shaft and blades to keep the garbage rotating during the process. After drying, the garbage is thrown away in as unobjectionable a manner as possible. The kind of garbage collected is organic, and under the contract must not contain more than 10 per cent. of other solid matter.

The Author gives various figures and data, showing quantities treated during different periods.

A. P. H.

The Sewage Works at Gross-Lichterfelde and Treptow, and the Applicability of this Process for the Drainage of Slaughter-houses. JOHANNES SENFF.

(Gesundheits-Ingenieur, 15 February, 1900, p. 42.)

The Author describes the works at Gross-Lichterfelde for the biological treatment of sewage water by reference to a plan and section. The sewage water enters first into a catchpit for the sand, and then passes into the receptacle for suspended and floating impurities, the exit from which is at the bottom of the chamber. It next flows into the covered store-tank, which is of sufficient size to contain the whole of the sewage produced in twenty-four hours. The tank is so arranged that the next day's flow displaces that collected on the previous day, and owing to the very slow motion a fairly perfect settlement is obtained, and the foul water is clarified by simple subsidence. The effluent is drawn off by a pipe which dips for some depth into the storage-tank, and thus both the sludge and the floating matters are kept back. Putrefaction goes forward in the storage-tank, and the clarified effluent passes on into the oxidizing chamber. This is a filter-bed, lightly roofed over. The filtering materials consist of a layer of gravel about one foot in depth above the drainage-pipes at the bottom, and above the gravel is a deep layer of coke-dust. There is a valve on the bottom drain-

pipes, so that the filter can be allowed to fill gradually. This causes the air contained in the pores of the coke to bubble up through the liquid, and the oxygen gas serves to stimulate the production of micro-organisms. As soon as the bubbling ceases, the valve is opened and a perfectly clear liquor, free from combined ammonia and sulphuretted hydrogen, escapes. It is necessary after its use to allow the oxidizing chamber a period of rest, in order that the coke may again become filled with air, and for this purpose two filter-chambers are constructed side by side and employed alternately. In order to render the purification as complete as possible the effluent passes through a second set of filters placed at a lower level, and it is finally collected in a reservoir in which there are a number of gold fishes, which appear to thrive and to do well. The works at Treptow are identical in character, but the clarification is not so perfect. The Author discusses the modifications required to adapt the process for the drainage of the slaughter-houses at Königshütte, and he states his conviction that this method of sewage treatment is well adapted for the purpose.

G. R. R.

Comparative Cost of Illumination by Means of Acetylene Gas and Petroleum. W. WEDDING.

(Gesundheits-Ingenieur, 28 February, 1900, p. 59.)

The chief objection raised against acetylene gas for illuminating purposes is its relative costliness, and the Author states that the inflated price of calcium carbide has led to this condition of affairs. The experiments here described were undertaken on behalf of the Berlin municipal authorities in respect of the cost of the illumination of the sewage irrigation works at Grossbeeren by means of acetylene gas, which has recently been substituted for the former system of petroleum oil illumination. Full details are given of the number of lamps, the cost of the installation in each case, the photometric power of each illuminant (which last was about the same), the prices of raw materials, and the annual working charges, which were £74 8*s*. for the acetylene and £60 4*s*. for the petroleum, or £14 4*s*. in favour of the latter. It is pointed out that this must not be regarded as a proof that the former system is to be preferred to the lighting by means of acetylene, for various other matters have to be taken into consideration which are here discussed. The Author is of the opinion that the use of acetylene may be safely recommended for new works.

G. R. R.

Schumburg's Process of Purifying Water. A. Pfuhl.

(Zeitschrift für Hygiene, 1900, p. 53.)

Among the various attempts to rapidly purify water by chemical means, that is to say, to destroy therein all deleterious germs without injury to its appearance or its taste, the process introduced by Dr. Schumburg in 1897 takes the first place. Recent improvements, indeed, have rendered this plan applicable for every practical requirement. Schumburg was commissioned to test in the Emperor William's Academy at Berlin all the chemical processes of water purification, and he ascertained that in five minutes by the use of bromine solution nearly every species of water bacteria and all known pathogenic germs found in water were destroyed, and that in another five minutes such water could be rendered clear and tasteless by the addition of ammonia. In carrying out this treatment, it was necessary to add to each litre of water 0·06 gram of free bromine in the form of bromide of potassium solution. In order to remove the bromine, and to render the water palatable, a like volume of 9 per cent. solution of ammonia is required. In the case of very hard and very polluted water, rather more bromine was needed; in fact, so much as would render the water a pale straw-colour. The taste of water treated in this way could scarcely be distinguished from the sample before treatment; it is absolutely clear, and contains so small a quantity of bromides as to be entirely devoid of injury to health. One kilogram of bromine suffices for the treatment of 16,000 litres of water (3,520 gallons). This process was specially advocated for water for army purposes, for sterilizing water in the tropics, for use in ships' tanks, in suspected or infected harbours, and in the case of epidemics, etc. The Author describes the mode of putting-up sample cases of the necessary reagents in wooden boxes, or, in the case of large quantities, in metal cases, with measuring instruments, etc. The results of numerous tests are set forth in tables, and certain necessary precautions and conditions, with respect to the successful employment of the process by troops on the march and others, are given in a series of conclusions. The Author states that the process provides the means of complying with every sanitary requirement at a most moderate cost.

G. R. R.

The Pollution of the Limmat by the Waste Water of Zürich. J. Thomann.

(Zeitschrift für Hygiene, 1900, p. 1.)

Some reference is made to the works of writers who have investigated the pollution of rivers by the sewage of towns; thus Frank has dealt with the effect of the "Sewage of Berlin upon

the Water of the Spree."[1] Several authors have discussed the influence of the waste water of Munich upon the purity of the Isar, and it has been proved in all cases that in the course of a further flow of a few miles beyond these towns the quality of the river-water has become greatly improved by a process of self-purification. In the same way the Elbe below Dresden, the Maine after passing Würzburg, the Rhine below Cologne, and the Oder, the Oker and the Danube, after previous pollution, have been found to possess marked powers of natural recovery in their downward flow towards the sea. In the year 1889 Schlatter carried out a series of investigations from January to the end of April upon the pollution of the Limmat,[2] and he proved that the river, even in a flow of but little over six miles, recovered from the effects of admixture with the Zürich sewage.

In the interval of ten years since the former inquiry, the circumstances have greatly changed, and it was considered expedient to undertake a fresh investigation into the degree of pollution, the effects of self-purification, and the extent of the river affected. The tests, which were partly bacteriological and partly chemical, were supervised by Prof. Dr. O. Roth. Dr. Bertschinger was responsible for the chemical tests, and the bacteriological analyses were entrusted to the Author. Zürich possesses a pail system for the removal of the excreta, and some account is given of the volume of water in the Limmat and its confluent, the Sihl, and the position of the outfall sewers. At the time of Schlatter's investigations the soiled water from about 67,000 people, having a volume of about 4 million gallons, passed into the river daily. At the present time the population amounts to about 125,000 persons and the volume of sewage to upwards of 13 million gallons per diem. Owing to the great increase in the sewage-flow the outfall has been extended for more than a mile, and it now enters the river at a point much lower down than formerly. The Author describes the mode of conducting the tests, which extended over 12 months, and he gives numerous tables of bacteriological and chemical analyses. He states, in conclusion, that whereas Schlatter had often found the river 6·21 miles below the sewer-outfall to have fully regained its original purity, he only observed upon one occasion that in the flow of 9·32 miles below Zürich the water of the Limmat contained less germs than it did above the town. The germ-contents at the most distant station were generally half as much again as they originally were before the river became polluted. The conditions are therefore much less favourable than they were 10 years ago, but it cannot be alleged that the impurities are such as to preclude the discharge of the sewage water into the Limmat. A sketch-map is appended giving the positions of the various stations for taking tests.

G. R. R.

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[1] Minutes of Proceedings Inst. C.E., vol. xcii. p. 473.
[2] *Ibid*, vol. ciii. p. 450.

Prenzlau Water-works. H. Sheven.

(Zeitschrift des Vereins deutscher Ingenieure, 1900, p. 33.)

Prenzlau is situated to the north of Lake Uecker, formerly the principal source of water-supply to the town, besides two springs, the Buller and another, providing 88,000 gallons per diem, hardly sufficient for one quarter of the population (20,000).

The new waterworks were to afford 484,000 gallons per diem, but are capable of delivering 719,400. The soil is alluvial, dotted about with little hillocks. The springs are about 1½ mile from the town; round and about them five artesian wells have been sunk in the following manner: first, a 10-inch iron pipe was driven down into the water-bearing stratum; within it a 7-inch pipe, provided at its lower extremity with a length of 6-inch perforated copper pipe, covered with copper gauze, was inserted, the outer pipe being then drawn nearly to the surface of the water-bearing stratum, the space between the two being filled up with coarse sharp sand. This outer pipe leads into a 10-foot masonry well, provided with a water-tight concrete floor; the inner pipe passes through a stuffing-box to the top of the well, which is carried up above the surface and surrounded with an earthen mound. All five wells are connected by underground mains with the storage well at the pumping-station, where the water is pumped into the filter-tanks, and after aeration is delivered into tanks and thence forced through the mains to the town, the surplus being stored in the water-tower, a masonry structure supporting a circular tank of 88,000 gallons capacity. Two compound horizontal engines drive the combined lift and force pumps. Begun in July 1898, the works were completed the following June at a total cost of £25,355. The Paper is illustrated by plans, elevations and sections of the wells, pipe track, engine and filter-houses and water tower.

W. A. B.

The New Gasworks for the Town of Zurich at Schlieren. A. Weiss.

(Schweizerische Bauzeitung, 1899, pp. 186 *et seq.*)

This is a long Paper, appearing in the issues of several months, and a very complete description of the new gasworks is given by the gas engineer to the town of Zürich.

After describing the general arrangement of the buildings the system of gas production is treated in detail. One of the chief features is the endeavour to avoid hand-labour as much as possible. An elaborate system of conveyors and lifts has been installed to deal with the coal as it arrives and the coke after it is produced.

The retort-house is placed next to the coal stores, and the latter are constructed with a floor sloping at 25° to 32°, so that the coal slides down by gravity and then passes on to special travellers having a sloping movement, which the Author considers very satisfactory, as it takes very little power. From the level of the cross channels the coal is carried by a bucket elevator to a transporter, consisting of an endless chain fitted with vertical shovels, which push the coal along a channel and deliver it to hoppers over the retort-house. The capacity of the apparatus is 14·4 tons per hour. No hand-labour whatever is used in the transport of the coal.

The coke store is very large to avoid the loss in quality of the coke when piled out of doors. The glowing coke falls from the retorts into small wagons, each having a capacity of two or three retorts, 570 lbs. to 660 lbs., and is then taken by a bucket elevator to be broken and sorted.

In a separate building are installed the coolers, exhausters and washers, arranged in two sets, each capable of dealing with 883,000 cubic feet to 1,060,000 cubic feet per day of 24 hours. There are two air coolers and two Reutter water coolers; in the former 2·5 square feet of surface are required for every 100 cubic feet cooled in 24 hours; but the Author prefers the water coolers, each of which deals with 389,000 cubic feet in 24 hours. Tar washers of the Dary type are used, and a carburetting plant on the system of Dr. Leybold has been put in large enough for a production of 3,531,000 cubic feet per day.

It is intended to use three gasholders, each of a capacity of 883,000 cubic feet, and two are now built; details of the construction are given.

The steam boilers are fired with waste coke and dust, and this is burned upon special grates of the Kudlicz type. In the engine house are two tandem steam engines, each of about 70 HP., and these drive two three-phase generators, each of 50 kilowatts. Current is supplied for power and light, the lifts, travellers and conveyors being all driven by electric motors, and the place is lighted by electricity as well as gas. There are twenty-three motors using 207 HP., the smallest being 1·5 HP. and the largest 15 HP.; there are also 49 arcs, 281 glow-lamps and 90 gas-burners.

A plan of the gas mains is also given. The total cost of the works was about £246,800, and about 200 firms were employed. The plant is arranged at present for an output of 1,770,000 cubic feet per day of 24 hours, but the buildings are large enough for an output of 3,531,000 cubic feet per day.

The Author considers that it is becoming more essential to add water-gas to the output, and this will be done shortly.

E. R. D.

Christiania Water Supply.

(Teknisk Ugeblad, Christiania, 1899, pp. 395–396.)

The present supply of drinking water is obtained from streams flowing from Sogn Pool and Maridal Pool. The watershed of the former is only 9½ square kilometres (3½ square miles), and the regulation of the flow is sadly defective, owing to riparian rights. Maridal stream, which would otherwise suffice, is all wanted for industrial purposes; and there are difficulties in the way of increasing the supply from Akers River. Investigations carried on for a number of years by the engineer of the Employers' Association have led to the conclusion that from three adjoining watersheds water can be diverted into Maridal stream at a fraction of the cost of appropriating more water from Akers River. At present their water flows down Hakedal River into the River Glommen; it is of the same excellent quality as the Maridal water, since the gathering ground is of the same volcanic formation. As these watersheds contain no hollows which might at a reasonable cost be enlarged into storage reservoirs of sufficient capacity, part of the rainfall in wet years must be stored for dry years in the lakes situated along Maridal stream, which can be dammed up to a higher level. In a dry year the rainfall may amount to only 75 per cent. of the normal, while the outflow at the mouth of Maridal may be only 62 per cent. of the rainfall. In a bad year therefore the available supply may be barely half the normal rainfall; larger reservoirs are accordingly required for enabling an increased supply to be ensured. Works with this object have been undertaken for the corporation by the Employers' Association, to be completed in the course of 17 years at an estimated cost of about 2·9 million kroner (£161,000), of which 2 million kroner (£111,000) will be for storage reservoirs in the three watersheds and for conduits therefrom, and 0·9 million kroner (£50,000) for storage in Maridal; and the contractors are to receive altogether 3 million kroner (£166,666) in the course of 19 years. A steadily increasing supply is guaranteed as the work progresses; and meanwhile the town is empowered to draw as much as may be needed from Akers River. It is expected that the supply ultimately obtained from the three watersheds will amount collectively to 925 litres per second (17½ million gallons per day). Adding the 310 litres per second (5¾ million gallons per day) which the town is at present entitled to draw, the future supply available will suffice for a population of about half a million. Christiania is thus fortunate in comparison with the larger European towns, in many of which the water supply has cost ten times as much; while the price per 1,000 gallons will be even lower in Christiania than it was 15 years ago for the existing supply of 5¾ million gallons per day.

A. B.

Development of Artificial Lighting. C. KJÆR.

(Ingeniøren, Copenhagen, 1899, pp. 277–81 and 283–87.)

Starting from the oil lamps of antiquity and their use latterly of petroleum, this long historical and critical review notices Murdoch's invention of gas lighting in 1792, and traces the subsequent development of artificial lighting down to the electric exhibition in Paris in 1881, which was followed by the rapid spread of electric lighting in Europe.

The Welsbach mantle in 1886 provided an incandescent gas-lamp, which not only reduced the consumption considerably, but also gave a better light than the electric glow-lamp. It opens a wide future for water gas, which, though of no illuminating value when non-carburetted, develops in this condition the high temperature necessary to make the mantle glow. In the Dellwick process the object is to produce carbonic acid during the blowing, whereby more than three times as much heat would be developed as when carbonic oxide only is formed from the same quantity of carbon. Though this aim has not yet been successfully realized in practice, from 13 to 20 per cent. of carbonic acid has been reached, against only about 6 per cent. in the older processes, while the yield of gas is likewise greater, and the blowing is reduced to only about 1¾ minute for 7 to 8 minutes of gas-making. In Copenhagen the make of water gas is about 700,000 cubic feet per day. Per thousand cubic feet Dr. Leybold of Hamburg gives 0·46 to 0·54 penny as the whole cost of production for carburetted water gas of 16 candle-power, and 0·64 to 0·76 penny for 20 candle-power, including 0·15 penny for wages in each case. It seems likely that lighting by water gas in combination with the Welsbach mantle will enter upon a new phase, and thereby secure a place alongside of electric lighting for a long time to come.

Acetylene gas is now produced at the rate of about 4·8 cubic feet per lb. of calcium carbide, and the production of the carbide itself requires an average expenditure of about 2·2 E.HP. hours per lb. Where ordinary gas or electricity is not available, acetylene certainly has its advantages.

Electric lighting of lamps in series has been accomplished to a certain extent by Fr. von Hefner-Alteneck with differential arc-lamps, and also with shunt arc-lamps, but the latter to the number of two or three only. Lighting in parallel renders each lamp independent of all the rest, and is certain to be employed in future, either by itself or in combination with lighting in series. Latterly the aim has been to reduce the consumption of electricity by constructing the lamps for higher tension and lower strength of current; 220 volts are now being employed instead of 110, and double the number of lamps are supplied through the same

conductors. In the American Jandus lamp[1] the arc and carbons are contained in a closed transparent cylinder, from which the air is excluded; instead of the usual 10 to 16 hours the carbons here last 100 to 200 hours, and their points are five to seven times further apart; but the economy is less, because the light has to pass through the enclosing cylinder, and more of it is thrown upwards by the longer arc.

The fact that magnesia, lime, and other metallic oxides are insulators while cold, but when heated to a dazzling white heat become good conductors long before their melting point is reached, was taken advantage of by Professor Nernst of Göttingen in his invention in 1898 of a glow lamp on a new principle.[2] A little stick of calcined magnesia, 7 millimetres (0·28 inch) long and 1½ millimetre (0·06 inch) diameter, when heated in open air by an alternating current of 118 volts and 0·23 ampere, or 27 watts, gave 31 candle-power, or 1·14 candle-power per watt. Such a magnesia stick hangs freely and vertically within a fixed cylindrical bell of insulating material, which is wound inside with a coil of platinum wire connected in parallel with the main circuit. Attached to the top of the bell and concentric therewith is an upright solenoid, in which the iron core is suspended by a helical spring from a fixed point overhead, so as to move up and down within the magnetizing coil; from the bottom of the core the magnesia stick is suspended inside the bell by a wire connected in series with the magnetizing coil; and from the bottom of the magnesia stick another wire is led to the main circuit. On closing the circuit for lighting the lamp, the current at first passes only through the platinum coil inside the bell, because the parallel circuit through the solenoid and magnesia is blocked while the latter is still cold and non-conducting; but the heat from the platinum coil being concentrated upon the magnesia renders it in a few seconds hot enough to become conducting. The current then passes through it to the solenoid, the iron core is drawn down into the centre of the solenoid, and the glowing magnesia suspended from the core, being thus lowered clear below the bottom of the bell, gives out its light all round. By this movement the platinum coil is automatically cut out of circuit, and the whole current henceforth flows only through the magnesia and the solenoid. The magnesia suffers no diminution in brilliancy from length of burning in the open air, as the metallic oxide undergoes no change by heating in air. In all likelihood the Nernst lamp will supersede neither the arc nor the incandescent lamps of older construction, but will take a place of its own, intermediate between these.

A summary of his review is presented by the Author in the accompanying tabular form.

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[1] Minutes of Proceedings Inst. C.E., 1898, vol. cxxxiv. p. 474.

[2] *Ibid*, 1899, vol. cxxxviii. p. 544; and Society of Arts Journal, 1899, vol. xlvii. pp. 253–260.

COMPARATIVE COST OF 500 CANDLE-POWER-HOURS IN DIFFERENT MODES OF LIGHTING.

Kind of Light.	Lamps and Burners most frequently employed.		Cost in Denmark.		Heat developed per Candle-Power per Hour.	
	Candle-Power.	Consumption per Hour.	Lighting Medium.	500 Candle-Power-Hours.		
				Pence.	Calories.	Th. U.
Electric arc	650	422 watts	7·31*d*. per kilowatt per hour.	2·37[1]	0·562	2·24
" incandescent	16	50 "		11·42[2]	2·700	10·75
" " (Nernst)	50	75 "		5·48	1·296	5·15
Retort Gas—						
Argand burner	32	8·83 cubic feet.	5*s*. 0*d*. per thousand cubic feet.	8·31	42·12	168·0
Ordinary flat-flame burner	16	5·64 cubic feet.		10·64	54·00	215·0
Welsbach incandescent mantle	50	3·35 cubic feet.		2·02[3]	10·26	40·7
Non-carburetted Water Gas with Welsbach mantle	50	5·29 cubic feet.	2*s*. 2*d*. per thousand cubic feet.	1·40[3]	7·80	31·0
Acetylene Gas	50	1·14 cubic feet.	2·42*d*. per lb. of calcium-carbide, equivalent to 4·8 cubic feet of acetylene gas.	5·76	9·02	35·8
Petroleum	30	0·18 lb., say 0·0225 gallon.	9·68*d*. per gallon.	3·53	23·00	91·4

Under favourable circumstances the ordinary incandescent lamps utilize as light only about 7 per cent. of the energy expended, and the Welsbach gas light only about 2 per cent.; the rest goes in heat. The ultimate aim of science is therefore the production of light alone, without heat; and from the close analogy between electricity and light it is conceived that this aim may in the future be realized by means of electricity. In the visible solar spectrum the undulations or waves producing light range between 450 and 700 billions per second. Herz obtained about 60 million electric alternations or waves per second, and is believed to have subsequently reached 50,000 millions. If

[1] Add 0·205 penny for renewal of carbons.
[2] Add 0·286 penny for renewal of lamp itself.
[3] Add 0·133 penny for renewal of mantles.

their number could be increased to that of light, the electric vibrations ought also to produce light. Tesla endeavoured to give a practical turn to Herz's investigations by constructing alternate-current dynamos with high tension and a frequency of over two million alternations per minute; later he obtained far better results with a vibrating discharger of a Leyden jar, whereby he is said to have actually succeeded in producing light without material development of heat.[1]

A. B.

Method of Testing the Electrical Plant at Buffalo and Niagara Falls.

(Sibley Journal of Mechanical Engineering, vol. xiv. p. 253.)

A power test on a very large and complete scale was carried out in February, 1900, by the engineering department of Sibley College, U.S., on the electrical power plant of the Buffalo Railway Company. Details have not yet been published. The plant consists of: (*a*) sixteen dynamos, driven by ten steam engines, with an aggregate of 6,000 HP.; (*b*) four rotary converters for changing the alternating current from the Niagara Falls turbines to a direct current; (*c*) a storage battery, having a capacity of 3,000 ampere-hours. The object of the latter was to equalize the load thrown on the electric generators, especially morning and evening, when the maximum power was required. The engines comprised one 250-HP. compound, and six 500-HP. cross-compound, belted to thirteen of the generators, and three 1,000-HP. cross-compound engines directly connected to the other three generators. Steam was supplied from sixteen Babcock and Wilcox boilers and two marine type boilers. The coal was fed into the boilers by Roney's mechanical stokers, to which it was supplied by automatic conveyors.

Upon this plant three tests, each of 24 hours' duration, were made by eighty students of the College, under the direction of Professors Ryan and Carpenter. The experimenters were divided into three sets, for testing respectively the boilers and auxiliary machinery, the engines, and the electrical plant. In the boiler trials the consumption of feed-water and of coal, steam-pressures, weight of water evaporated, and heating value of the coal were determined, and the flue gases analyzed. In the engine tests the consumption of steam per HP.-hour was noted, and in the electrical trials the output, effect of the storage battery on the consumption of coal, and the load factor, *i.e.*, the ratio of mean average load to maximum average output per 24 hours.

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[1] Tesla: Untersuchungen über Mehrphasen-ströme und Wechsel-ströme höher Spannung und Frequenz.

It was particularly desired to determine the value of the power obtained from the Niagara Falls, and the use of the storage batteries in regulating the speed of the engines, and giving a steadier load. To obtain this the first run of 24 hours was made under normal working conditions, namely, using 1,800 HP. from the Niagara water-power, and 5,500 HP. from the engines and the storage batteries. In the second day's run the power from Niagara was not employed, all the power being supplied by the engines and batteries only. During the third 24 hours' test the batteries were shut off, and the engines worked alone. By these means the cost of power under present conditions was determined. During the three days' tests, 8,000 indicator diagrams were taken.

Although conducted on so large a scale the trials were entirely successful and no hitch occurred.[1]

B. D.

Electric Working of Sidings. OTHEGRAVEN.

(Organ für die Fortschritte des Eisenbahnwesens, 1899, p. 218.)

The Author commences by discussing various mechanical and electrical arrangements that have been tried with a view to simplifying and accelerating shunting operations on sidings, and leads up to the method which it is the principal object of his Paper to describe.

To illustrate the main outlines of this method, an example of its application to a simple case may be taken. Suppose communication is required between the officials on a shunting neck and the adjoining signal-cabin. In the signal-cabin is a glass-fronted frame divided into squares, behind each square is an electric glow-lamp, and in front, on the glass, are painted symbols —one to each square—which may be, for example, numbers corresponding to the numbered roads of the sidings.

In a convenient situation close by the shunting neck is a similar frame numbered in the same way, but instead of a lamp to each number there is a switch by which the circuit supplying current to each of the lamps in the signal-cabin frame may be made or broken. If now, for example, the shunter attending to a train in the neck wishes to indicate to the attendant in the signal-cabin that the next wagon is to go into No. 5 road, he simply operates the switch in front of No. 5 square in the frame above mentioned to turn the current on, when No. 5 square in the signal-cabin frame is illuminated, thus drawing the attention of the signalman.

The Author describes the working of a group of fifteen sidings by this method. Five men are required, one on the shunting

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[1] It is presumed full details of the tests will follow. Niagara is about 22 miles from Buffalo. A copper conductor on poles is used.—B. D.

neck, the pointsman in the signal-box, and three others, each of these latter having to attend to three or four pairs of points. No shouting is required and no chalking of numbers on the wagons.

The advantages of such a system are the certainty and rapidity of communications, resulting in rapid handling of traffic, comparative independence of the state of the weather, and less risk to the men engaged.

W. B.

A Modern Central Electric Station. H. H. HUMPHREY.

(Engineering News, New York, 18 January, 1900, p. 35.)

The Author describes the plant designed by him, and in process of construction for supplying the town of St. Louis with power and light. The three-wire system of 220 volts and 440 volts direct current is adopted, the advantage being the large increased area of town possible to be served. Hypothetical power-curves were drawn out, giving the power required for arc and glow lighting, and for power. The three were then combined into one, showing the total power necessary at different periods of the day in the depth of winter.

The power plant consists of one 500 HP. compound engine and two 750 HP. Willans engines. There are four 500 kilowatt generators, so arranged that any one can be driven by the large engine, should one of the smaller ones be out of use. The efficiency of these generators varies from 88 per cent. at quarter load to 94 per cent. at full load, while they are guaranteed to stand an overload of 25 per cent. for two hours 33⅓ per cent. for one hour, and 50 per cent. momentarily, without undue heating. The storage batteries consist of 280 cells, and work the entire load from 1 A.M. to 5 A.M., being charged during the early hours of the afternoon. The glow lamps used are mostly of 235 volts, as also are the arc lamps, though the latter work better with two in series with a potential of 235 volts for the two, than singly at that pressure. The whole plant has been designed upon the most economical basis; the saving in copper due to the high pressure system being equal to half the cost of buildings and plant. At the station itself all auxiliary machinery is driven electrically, steam being only used in the cylinders of the large engines. By this means it is estimated that a saving of 10 per cent. in the entire working expenses is effected. Fuel economisers are used, which save about 25 per cent. of their cost per annum, with coal at 6*s.* 3*d.* per ton.

A. P. H.

A New Method of Compounding Alternators.

(Engineering News, New York, 4 January, 1900.)

In direct-current generators the drop of voltage under heavy load is due to various causes, among which is the decrease of resultant magnetic flux, owing to increased armature reaction, which takes the form of demagnetisation and cross-magnetisation. This can be largely overcome by compounding, by which the magnetising force in the field magnets is made dependent upon the total armature current, which is passed through a few turns round the magnets. The shunt part of the coils is superposed upon this. In an alternator the voltage drops under high load from the same causes, but with additional field distortion due to impedance. To remedy this a variation of the same device is adopted, the magnetic flux being strengthened as the generator current increases with the load. In the case under consideration, the alternator magnets revolve, whilst the armature is stationary. Rigidly connected upon the same shaft is a rotary converter. The alternator supplies 3-phase currents, the main portion being taken to transformers, whilst the smaller portion is converted into direct current by the rotary converter. This rotary current is led to the two slip rings for supplying the rotating field magnets of the alternator. In an alternator with constant magnetising currents for the field magnets, an increased load causes increased armature reaction and distortion of magnetic field, which is especially marked when the external load causes a lag in current behind its electromotive force. With this device, however, an increased external load produces increased current through the alternating side of the rotary converter, and if the primary current is out of phase, a still further increase is necessary to supply a given power. The direct current from the rotary converter is also increased, and the magnetic flux thereby strengthened. In practice, the direct current may be regarded as corresponding with the current through the series turns of a compound continuous current generator, while the current from the separate exciting apparatus corresponds with the shunt coils. The magnetising force in the armature field magnets is thus made to depend partly upon a constant current, and partly on a current proportional to the load. Lag in the primary current is specially liable to occur when the alternator is driving polyphase induction motors, and the system described here is especially applicable to that case.

A. P. H.

Recent Electrical Locomotives.

(Zeitschrift des Vereines deutscher Ingenieure, 1900, p. 376.)

The employment of electrical locomotives in certain cases has been frequently advocated in this journal.[1] The Author in this paper describes two such engines, one employed in shunting at the Hoesh Steel Works, and the other in the mines at Esch, in Luxemburg.

The shunting engine is of the usual form. The cab, which is furnished with windows on all sides, rests on a substantial frame; each axle is driven by a separate motor enclosed in a cast-iron casing provided with journals to receive the axle on one side while the other is supported on springs; thus the distance between the motor and the axle is constant, while a certain amount of play is secured.

The motors are primary current motors of 23 HP. working at 275 revolutions, the tension 500 volts, diameter of wheels 29½ inches, speed 6·83 miles, tractive force=21·6 cwts.; total weight, 8·86 tons.

The collector consists of a hollow aluminium rod, supported by two hinged parallelogram frames, the pressure regulated by five springs.

Special conditions affected the construction of the mining locomotive; all machinery to be 2·95 inches above rail-level and efficiently protected; sharp curves, and a varying level of conductor, to be provided for. The gauge is 27·55 inches, the motors 90 HP., speed 4·35 miles, and tractive power, 3·45 tons; total weight, 8·857 tons. Each axle is driven by a separate 45-HP. motor of 500 volts, making 525 revolutions. Provision is made for driving from both ends. The buffers are in the form of a segment of a circle, hinged on two bars. The entire engine is enclosed in a massive casing completely protecting all the working parts, which are fully illustrated and described in the Paper.

W. A. B.

The New Electricity Plant in the Zurich Polytechnic.

F. Largiadèr.

(Schweizerische Bauzeitung, 1899, p. 180. 7 Figs.)

Until quite recently the Polytechnic School at Zurich only possessed a small electrical plant suited for electrochemical research, and this consisted of a direct-current dynamo and two small secondary batteries. Owing to the great development of this branch of the science a larger plant was found desirable. Mono-

[1] Zeitschrift des Vereines deutscher Ingenieure, 1896, p. 773; and 1899, p. 170.

phase alternating current at 2,000 volts and a frequency of 50 alternations per second is brought in from the public mains to a transformer, so designed that pressures of 50, 37·5, 25, or 12·5 volts can be obtained on the secondary mains, and either the alternating current can then be delivered direct to the laboratory, or changed into continuous current by means of a rotary commutator; or both alternating and continuous currents may be obtained at the same time. The chief reasons for adopting the public supply were want of space for a private plant and the irregular use of current.

The transformer is of 30-kilowatt output and a diagram of connections is given in the original. The coils are so arranged that 50 volts and 500 amperes, 37·5 volts and 800 amperes, 25 volts and 1,200 amperes, or 12·5 volts and 2,400 amperes can be obtained. The transformer will bear a continuous overload of 10 per cent., and a momentary overload of 50 per cent., and the full load efficiency is 96 per cent. The distribution is so arranged that in the chief room 2,400 amperes are available; in the chief laboratory there is one point for 1,200 amperes and one for 600 amperes, and in the small laboratory one point for 600 amperes. The rotary commutator is the most interesting part of the installation. It consists of a direct-current machine, having at one side of the armature windings two slip rings for the collection of monophase current, and on the other side a collector with segments of the usual form with carbon brushes. The machine has six poles and runs at 1,000 revolutions per minute, with an efficiency of 87·7. It develops 400 amperes at 75 volts. It will not drive itself, but is actuated by a small synchronous monophase motor, which drives it by means of a leather-faced wheel working on a disk, thus allowing alteration of speed very easily.

The installation was designed by Profs. Wyssling and Lorenz.

E. R. D.

Electric Light and Power Station at Frederiksberg, Copenhagen. C. Winsløw.

(Ingeniøren, Copenhagen, 1899, pp. 295–298.)

A central engine-room is flanked on one side by boiler-house, and on the other by accumulator rooms with offices overhead. There are three inverted vertical triple-expansion engines with slide-valves, each of about 250 HP., supplied with steam by three Babcock and Wilcox boilers, each having 1,880 square feet of heating surface. In the yard at back is a cooling apparatus for the condensing water, which is raised into it by centrifugal pumps driven electrically; both condensing water and feed are pumped by electricity from a well about 120 feet deep, sunk by rope-boring to the limestone. Two of the engines drive each its own dynamo

of 200 kilowatts; one furnishes a current of 250 volts for lighting, the other of 550 volts for working the tramways. The third engine is coupled at each end to a dynamo of 150 kilowatts, one giving 250 volts and the other 550. Two current-transformers are provided for reducing the lighting tension to 125 volts. All the dynamos and transformers are outside-pole machines; the tramway dynamos are compound-wound, the rest shunt-wound. Along the engine-room wall, on the side next to the accumulator room, is the switchboard with the necessary measuring and distributing instruments. The battery for lighting is in a cellar of the accumulator wing, and comprises 136 cells, of which 48 are regulating cells; it has a capacity of 1,350 ampere-hours. Above it, on the ground-floor, is a secondary or buffer battery for the tramways, consisting of 265 cells, with a capacity of 260 ampere-hours, and capable of supplying for a short time a current of 520 amperes; under the greatest variations in the load it enables the engines to work regularly and economically. The third engine, driving one only of its two dynamos, serves as a reserve for either of the other two engines; in an emergency it can even take the place of both, to the extent of partially keeping both lighting and tramways going; and by coupling its two dynamos in series it serves for charging the secondary or buffer battery when necessary.

The lighting network is laid out on the three-wire system, with a potential difference of 220 volts between the positive and negative conductors. Nine mains lead from the central station to nine sub-stations or junctions, between which are carried distributing conductors through the streets. The current for the lamps is supplied exclusively from the accumulator battery, and the middle wire is led to its neutral point. To obviate unequal charging of the two halves of the battery, the lighting of the station itself is kept separate from the rest of the lighting, so that it can be thrown upon whichever half has least to do at the time. As a precaution against non-uniform discharge of the battery, the recharging of either half is provided for by the two transformers, which can transform the lighting tension into that corresponding with the half battery.

Close behind the electric station is the tramcar shed, containing seven lines of way which converge into one; the latter curves out into the two street lines. The shed has standing room for forty-nine motor tramcars; at each end are pits for getting under the car-trucks and motors. The aggregate length of the tramways is about 7 miles, of which 1¼ mile is single-line and the rest double. The rails are of Phœnix section, having great stiffness in proportion to their weight, scarfed with a half lap, and connected electrically at the joints by tinned copper ribbons, 40 inches long and 4 inches broad; the two rails of each pair are cross-connected every 33 yards, and the two lines of way every 109 yards. The rails are packed up with road metalling, with paving stones between and alongside, and with hard-burnt facing bricks fitting

the hollow side of the rail close up to the head. The grooves in which the wheel flanges run are drained of water at all depressions of the road. The overhead conductors or trolley wires are of copper, 0·315 inch thick, supported at a height of 21 feet upon cross or span wires, from 38 to 42 yards apart, which are carried on poles and on rosettes upon house walls. Switches are provided at every 550 yards, for cutting off the current from any section; also lightning conductors at the same intervals. Current is supplied to the overhead wires at two points, one near the station, the other about half a mile further, to both of which are laid underground feeders from the station. Each of the latter is large enough to supply the whole tramway system; the overhead wires are large enough to carry the current to the furthest extremity of the tramways, without the tension falling below the limit allowed. The current returns along the rails to the station. To ensure the trolley roller keeping always in contact with the conducting wire when running round curves, it swivels upon a pivot on the arm carrying it, and the arm itself also swivels upon a pivot on the side of the tramcar roof.

The tramcars being single-ended, to run in one direction only, require turning round at each end of every journey. They all have roof seats, and are closed at the front end; at the back is an open coupé. There are no steps to the front foot-plate on which the driver sits; consequently there is so much greater distance for the brakes to act, before the wheel guards reach any obstruction lying upon the line. Every car has two 27-HP. motors, one on each axle, which can be coupled partly in series and partly in parallel; the driving power and speed are varied by cutting out resistance. Braking is done electrically by short-circuiting the armature and the magnet windings; the current can also be reversed through the motor. By a single handle the driver rotates a drum inside a regulating box, in which the various connections required are made by an arrangement of contacts; for the reversing a separate handle is provided. A magnetic spark-extinguisher prevents the duration of an arc whenever the current is broken: a horse-shoe magnet is placed with its poles on each side of the point where the break of contact will occur, and is wound with a branch wire from the main circuit. The momentary current flowing through the magnet coil at the instant of breaking contact develops a magnetic field, by which the arc is deflected and extinguished. The same principle is applied for the lightning conductors on the tramcars and along the line. On the cars the ordinary circuit from the overhead conductor through the motor to the rails includes a coil whose self-induction prevents the passage of the high-tension lightning flash which would destroy the motor, while it allows the ordinary current to pass without hindrance. A separate route provided for the lightning contains two carbon points facing each other, placed between the poles of a horse-shoe magnet, which is shunt-wound with a branch wire from a graphite resistance inserted in the circuit below the carbons. The flash which strikes the arc between

the carbons is thus led through the magnet winding, where the resistance is least; the magnetic field thereby momentarily created effaces the arc, and thereupon also ceases itself.

A. B.

Production of Ozone. Dr. M. Otto.

(Mémoires de la Société des Ingénieurs Civils de France, 1900, pp. 149–220.)

The Author's own description of his rotary ozoners [1] differs somewhat from that given in a previous abstract,[2] and is of more recent date. He divides them into two principal classes:—rotary ozoners with movable electrodes; and rotary ozoners with stationary electrodes, acting either by what he calls "decoy" of the electric discharge that is to produce the ozone, or by interruption thereof. The principle upon which both classes alike act is that, if two electrodes connected with the two poles of a circuit of high potential are brought near enough to each other, an electric discharge will take place between them across the intervening space; and on then gradually increasing the gap, the discharge will cease when the gap becomes too wide. If an arc has been accidentally formed during the discharge, it will be broken by the wider gap.

In the first class, one of the two electrodes is movable, and the electric discharge streams direct through the air or oxygen in the space intervening between the two metal electrodes of differing potentials, without any dielectric being interposed between them. The horizontal form of this ozoner consists of a cast-iron casing, approximately of Ω section, cylindrical throughout the uppermost two-thirds of its circumference, where it is bored out; the remaining third opens into a bottom chamber, bolted down upon a base-plate; the whole constitutes the stationary electrode. A shaft running along the centre of the casing, and driven by a belt-pulley on one end, carries a series of thin steel disks, which collectively form the movable electrode. Each disk is notched out so as to form two opposite sectors; each sector is one-third of the circle, and the notches between them are each one-sixth of the circle. The disks are kept apart by thin cast-iron washers, and are fixed on the shaft helically, each being rotated through a small angle in advance of the one behind. The notches in the successive disks thus form a couple of wide deep helical grooves whose helical course obviates the shocks, both electrical and

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[1] As Dr. Otto's own French word for his machine which generates the ozone is *ozoneur*, there seems no reason why this should not be rendered into good English as *ozoner*: just as a boiler is spoken of as a good or bad *steamer*, and a fuel as a good or bad *heater*. The analogy of *oxidizer* and *carburizer* or *carbonizer* suggests that the word *ozonizer* should be reserved for the apparatus which *ozonizes* air or water: that is, impregnates them with ozone for sterilizing them.—A. B.

[2] Minutes of Proceedings Inst. C.E., vol. cxxxix, p. 445.

mechanical, which would occur if the grooves were parallel to the shaft. The ends of the casing are closed by two thick plate-glass covers, through which the working of the machine can be watched. The plummer blocks carrying the shaft are supported on insulated pedestals. To one block is connected one of the wires from a high-tension transformer; the other wire from the transformer is earthed, as is also the base-plate of the ozoner. The gap between the rim of the sectors and the cylindrical surface of the cast-iron casing may range from 5 to 100 millimetres (0·2 to 4·0 inches) in different machines; the ordinary clearance is 30 millimetres (1·2 inch), which with steel disks 1½ millimetre (0·06 inch) thick, having their rims bevelled on both sides to a fine edge, is suitable for regular working with currents of 25,000 volts. The air on which the electric discharge is to act for producing the ozone is admitted at one end of the casing through an inlet pipe in one side of the bottom chamber; and the ozonized mixture passes off at the other end through an outlet pipe in the opposite side. When the shaft is rotated and the electric current sent into the machine, powerful discharges stream across between the internal surface of the cast-iron cylinder and the rims of the steel sectors, while the alternating wide helical grooves are wholly inactive. If sparking occurs or an arc forms, it ceases as soon as it comes opposite the bottom chamber of the casing; there is thus immediate security against any danger. The revolving sectors present the appearance of a drum of fire surrounded by a glow of intense violet colour, which is cleft now and then by lightning flashes. The gas is well stirred up, and the machine does not get hot; after several hours' running it is not even warm. Except therefore the portion lost in the form of light, the whole of the electricity is utilized in the production of ozone. These rotary ozoners with one of the electrodes movable are also arranged vertically, and in pairs, occupying less floor space than the horizontal form. The insulation of the internal revolving electrode presents no difficulty; and as the whole of the outside casing is connected to earth, a bystander is exposed to no risk of danger from touching any part of the machine while working.

In the second class of ozoners, both of the electrodes are stationary. They are placed either too far apart for the electric discharge to leap across the gap until "decoyed" into doing so by an intervening conductor, which acts as a "stepping stone;" or so near together that the discharge will always stream across, except when interrupted by an intervening insulator. For either plan, two series of electrodes, alternatively positive and negative, in the form of annular disks carefully insulated, are fixed on annular diaphragms inside a horizontal cast-iron cylinder. On a revolving shaft running along the axis of the cylinder are mounted a series of disks, one rotating midway between each pair of electrodes; in each disk sixteen sectors are cut out, leaving sixteen radial arms; the length of the arms is equal to the radial breadth of the annular electrodes, and the diameter of the solid centre of

the disk is equal to that of the central aperture in the annulus. The air is thus compelled to circulate round the faces of the electrodes and rotating disks, in a zigzag course from the inlet orifice at one end of the cylinder to the outlet at the other. The facing surfaces of the electrodes are studded with projecting spikes or radial blades or serrated arcs, which are arranged in sectors to correspond with the arms or spaces of the rotating disks. The face of each electrode thus presents sixteen projecting armatures for electric discharge, separated by alternate recesses from which no discharge takes place. In the "decoy" ozoner, the rotating disks are conductors, and every arm as it comes between a pair of armatures forms a midway stepping-stone, enabling the discharge to get across in two steps where it otherwise could not do so in a single stride. In the interrupting ozoner, the rotating disks are insulators, through whose apertures the discharge streams freely across, and is interrupted by every arm that comes between the armatures, which also breaks any dangerous short-circuit that may have been formed. The high-tension current from the transformer is supplied to each pair of electrodes through insulated wires. The principal advantage of these ozoners with both electrodes stationary is the facility they afford for adjusting the electrodes to a uniform distance apart throughout the machine.

The percentage of pure ozone contained in the gaseous mixture delivered from the ozoner is determined in any one of four ways:—either chemically, by testing with potassium iodide; or optically, by observing the intensity of the blue colour due to the ozone in the mixture; or volumetrically, on the principle that two volumes of ozone heated to 250° C. or 480° F. are decomposed into three volumes of oxygen; or barometrically, on the same principle that the density of ozone is half as much again as that of oxygen. On the last plan a continuous record is obtained by a self-registering instrument.

For the purification and sterilization of drinking water by ozone a twofold method is employed, in which a set of mixers and a nest of trays are used in succession. The mixer is constructed like a Giffard boiler-injector, with two concentric cones producing a thin annular downward jet of water, which is surrounded by a current of the ozonized air; the intermixture of the water and air is thus secured. The minutest percentage of ozone in the air renders the issuing stream of ozonized water luminous in the dark, owing to the destruction of microbes and organic matter; the luminosity is much greater if the ozonized air contains 5 or 6 milligrams of ozone per litre (2 to 2½ grains per cubic foot, or say 0·4 to 0·5 per cent. by weight). The partially ozonized water issuing from a set of ten mixers is collected in an elevated covered tank, where the unabsorbed ozone separates out, and is led down to the bottom of a tall absorbing chamber containing a nest of from twenty to fifty large shallow trays; the water from the tank is delivered into the top tray, and overflows thence into the successive trays beneath, encountering throughout

its downward course the ascending current of ozone, of which it absorbs a further quantity, whereby its sterilization is completed. This twofold method suffices for 1,000 cubic metres (220,000 gallons) of water per day. For larger quantities the tall absorbing chamber and trays are replaced by a long tunnel, in which the water is broken up into a succession of miniature cascades, exposing a large extent of surface to the sterilizing action of the ozonized air pervading the entire tunnel. In connection with this branch of the subject, three Tables are quoted from Professor Balestre, director of the Nice Health Office, giving the mortality in 121 of the principal towns in Europe and America during the decade 1887–1896; they show severally per thousand inhabitants the general mortality, and that due to typhoid fever and enteric; and also per thousand deaths the number due to typhoid fever and enteric. Cairo ranks worst, Croydon best, and London better than either Paris or Berlin or New York.

The principal applications of ozone are dealt with at considerable length:—bleaching, dyeing, and cleaning of fabrics; mellowing of wines, spirits, and beer; oxidation of oils, perfumery, and colouring materials; preparation of drinking water, ice, and iodoform; purification of air in hospitals and private houses. At the Boucicaut Hospital in Paris apparatus has been put up capable of ozonizing 1,400 cubic metres (50,000 cubic feet) of air per hour. For domestic use ozone is supplied in two-gallon jars, fitted with a hand syringe for discharging it at pleasure into the atmosphere of a room.

A. B.

Production of Ozone. X. GOSSELIN.

(Mémoires de la Société des Ingénieurs Civils de France, 1900, pp. 221–8.)

Commenting upon Dr. Otto's Paper on this subject (*ante*, p. 407), the Author questions whether the plan of rotating one of the electrodes in the ozoner under so high a potential difference as 25,000 volts is compatible with the good working of the apparatus, owing to the difficulty of maintaining the insulation of the rotating parts under so great a tension. As the only object of the rotation is to break the arcs which short-circuit the electrodes, he would prefer to prevent the striking of any arcs, and to get rid of all moving parts in the ozoner. In his own experiments he has found glass an ideal insulator; and in its practical use in his works at Emmerin he has never succeeded in piercing a plate of glass by electricity, however thin it might be. The projecting spikes studding the faces of the stationary electrodes must be difficult to adjust so as to be flush all over the face. The sterilization of water, which constitutes the principal aim in the production of ozone, is no easy matter. In other oxidizing processes, chemical affinity obviates the need of intimate intermixture of the ozone

with the liquid treated. Water enjoys no such advantage, nor is ozone sufficiently soluble in it to ensure its diffusion throughout the whole of the liquid; every particle of organic matter in the water requires therefore to be brought into direct contact with the ozone, in order that the latter may exert its oxidizing action. Hence the need of securing the most intimate intermixture by mechanical means. Having himself tried spraying a jet of mixed water and ozone, he has found this plan capable of yielding good results; but the pressure of two atmospheres, necessary to be employed for spraying fine enough, is too high for practical success in dealing with large quantities of water; the same objection applies to the use of centrifugal turbines for effecting the intermixture. Moreover all metallic surfaces are oxidized by ozone, even when it is dry, and still more rapidly when it is accompanied by moisture; nor does enamel protect them effectually. Of the absorbing nest of trays the Author thinks highly, as a means of securing molecular intermixture of water and gas within only a few feet height of fall. For efficient action in destroying germs, the ozone must be produced in a sufficiently concentrated state by the ozoner. The cost of ozonizing less pure water is not so great as that of bringing purer water from a great distance through pipes, when the whole of the items of expenditure are taken into account in each case; and works capable of sterilizing 100,000 cubic metres (22 million gallons) per day can easily be carried out. The ultimate conclusion is that at the present time water can be sterilised practically by ozone with commercial success, and that when so treated it is perfectly safe for drinking.

A. B.

Tønsberg Electricity Works. EINAR RASMUSSEN.

(Teknisk Ugeblad, Christiania, 21 September 1899, pp. 407–413.)

While a number of other towns in Norway have previously established electric stations, Tønsberg (50 miles south of Christiania) is the first in the country at which gas has been adopted for the driving power. The works were started in 1898, and in December of the same year the supply of electric current commenced. Gas is made on Dowson's plan, in two generators, one suitable for 160 HP., and a smaller for 40 HP. in reserve and for summer use. Steam at 5 atmospheres pressure above atmosphere is supplied by either of two small vertical boilers, the other being kept in reserve. The generators are fired with best anthracite; the gas after being cooled and purified is stored in a small gas-holder for the supply of the gas engines. The gas-holder regulates automatically both the pressure of the gas and the rate of its production; the latter is controlled by a valve in the steam-pipe between the boiler and the gas generator, which is

opened or closed by the fall or rise of the gas-holder bell. The attendant has only to look after the firing of the boiler, and to keep the layer of coal thick enough in the generator. There are two single-cylinder gas engines of 45 HP. effective, with electric ignition by an induction apparatus, and with a large fly-wheel running at about 150 revolutions per minute; they are started by compressed air from an air vessel in the engine-room. Water for the boilers, purifiers, and cylinder-jackets is raised from a well by a centrifugal pump driven by electricity. Each gas-engine drives through belts two shunt dynamos of about 11 kilowatts; they make about 1,200 revolutions per minute, and produce a current of 100 amperes at 110 volts. The switchboard is made of white marble plates framed in angle-bars, with as little wood about it as possible. Besides the switches, fuses, and meters, there are two self-acting interchangers for the accumulator cells; also a shunt regulator for each of the four dynamos, whereby without altering their speed their tension can be increased to 160 volts for charging the accumulators. The battery-room is over the gas-generator room. It contains 132 cells, 66 on each side of the middle wire, having a capacity of 455 ampere-hours for discharging in 10 hours, and a maximum current of 112 amperes in charging and discharging. The battery is large enough for the whole of the night and early morning work, thereby saving both attendance and driving power. From the switchboard the mains, insulated with vulcanized indiarubber, are led up to the roof; thence into the town bare copper wires are carried overhead on fir poles. The lighting wires are separate from those for power, so that the lighting is not affected even by coupling motors working under very variable loads. The lighting wires are calculated for supplying 1,500 incandescent lamps of 16 candle-power, and the power wires for about 40 HP. The loss of pressure in the feeders is 10 per cent., and in the distributing mains 2 per cent. For the protection of the low-tension telephone and telegraph wires, two 4 millimetre (0·16 inch) galvanised iron wires are carried over the whole system, which are earthed at several points. Fuses melting with a current of 0·3 ampere are inserted at all junctions of low-tension mains, both at the telephone station and at the subscribers' houses. In the streets are 32 arc lamps of 4½ amperes, which are on a circuit of their own controlled from a switchboard in the municipal fire-engine station, whence they can be lighted and extinguished in three groups. They are shunt lamps with stationary focus, and burn for 16 hours. With the central station are at present connected 1,200 incandescent lamps, 42 arc lamps of 3 to 6 amperes, and 12 electro-motors collectively taking about 40 HP. For necessary repairs the works can be empowered by the municipal authorities to close entirely for a period of not more than fourteen days every midsummer, without compensation to their customers. Meters are provided at an annual rental ranging from 12½ kroner (13*s.* 10½*d.*) for 15 lamps

of 16 candle-power, up to 30 kroner (33*s.* 4*d.*) for 200 lamps of same power. The charge per hour for electricity for lighting is 5 øre per hectowatt (6·67*d.* per kilowatt), and for power 1·2 øre per hectowatt (1·6*d.* per kilowatt). At this price the cost per hour for incandescent lamps ranges from 1 øre (0·13*d.*) for 5 candle-power, up to 4·8 øre (0·64*d.*) for 32 candle-power; and for arc lamps burning in pairs from 8·2 øre (1·45*d.*) for each lamp of 200 candle-power and 3 amperes, up to 22 øre (2·93*d.*) for each lamp of 1,000 candle-power and 8 amperes; and for power about 9 øre (1·2*d.*) per HP. hour. The total cost of the works has amounted to 92,000 kroner (£5,111), made up as follows:—land £222, buildings and foundations £1,111, gasworks £638, gas-engines and dynamos £1,556, accumulator battery £528, switch-board and station mains and station lighting £333, external mains and poles, etc. £722. In addition there is the outlay for direct conductors and for meters; the latter have for the most part been purchased by the users. The street lamps have been paid for by the town. A second municipal station driven by gas is nearly completed at Hamar, 60 miles north of Christiania.

A. B.

Tests of Model Arches. DANIEL B. LUTEN.

(Engineering News, New York, 15 February, 1900, p. 106.)

The increased use of concrete arches in bridge construction led the Author to design an arch with wooden tie-bars, the latter traversing a river under the water-level. This method offers many advantages, among which are invariability of span, and the elimination of horizontal pressure upon the abutments, thus enabling the latter to be of lighter construction. The reaction between the arch and the abutment is entirely vertical, ensuring a more uniform distribution of pressure. The Author made a series of models of Portland cement, the dimensions being, span 4 inches, rise $\frac{5}{8}$ inch, thickness at crown $\frac{3}{8}$ inch, and length $2\frac{1}{2}$ inches. The form of the arch was circular, subtending an angle at 70° at the centre. The timber tie was formed of two pieces $\frac{1}{4}$ inch square, embedded in the cement at a distance $\frac{3}{8}$ inch below the arch springing, and secured by interlocking with a cross piece at each end. The arch, after being kept in moist air for 24 hours, was placed under water for 6 days, and then tested. The model was made to stand on horizontal supports, the reaction being entirely vertical. A tied arch withstood 110 lbs. placed at its centre before rupture occurred, whilst an untied one broke at 30 lbs., in the latter case the concrete acting simply as a beam. After fracture the two halves were placed together, still untied, and again loaded in the centre, under which circumstance it gave way on the application of one pound, indicating that the frictional horizontal reaction of the support before the arch was ruptured

contributed nothing towards the stability of the arch. The Author gives various formulas for the strength of loaded circular arched structures.

A. P. H.

Filtration-tests for Cements. L. DEVAL.

(Bulletin de la Société d'Encouragement pour l'Industrie Nationale, February 28, 1900, p. 267.)

It has been thought advisable, in the case of certain cements intended for use in sea-water, to test in a more rapid way the possibility of their deterioration under these circumstances by submitting them to a filtering action. In carrying out such experiments the practice hitherto has been to introduce the saline liquid under pressure into a chamber, hollowed out for this purpose in the test-briquette, and to cause the liquid to flow through the cement from the interior to the exterior. Mr. Le Chatelier considered it expedient to substitute for this mode of trial the system of testing explained by the Author. The pats or briquettes, which were in the form either of cubes or cylinders, were gauged so as to be as porous as possible and were immersed in the test-liquid. At the lower part of the cement-mortar a vertical tube was fixed which was used as an aspirator-tube, and by exhaustion of the air the liquid was drawn through the cement from the outside to the interior, thus reversing the ordinary procedure, as it was considered that by this means the injurious action would take place in the first instance on the outer surface of the cement under test, and that a definite result would thus be more speedily secured. It was thought also that by regulating the speed of flow through the cement during the period of the experiment, and by rendering the permeability of the test-substance as uniform as possible, the values obtained in the case of the different cements under trial might be rendered comparative. The results were, however, negative in character. In order to increase the permeability of the test-briquettes the cement was gauged with an equal weight of water and the paste was thickened in the hot bath; or, secondly, a mortar was made with one part of cement to four parts of fine Fontainebleau sand; or, thirdly, the cement was gauged with precipitated carbonate of lime or Spanish white, on which the saline liquids had no action. After the test-blocks had been moulded they were allowed to remain for several days in water to become indurated, and they were then immersed in the test-liquids, which were either artificial sea-water, a dilute solution of sulphate of magnesia, or a saturated solution of sulphate of lime. By lengthening the aspirator-tube, it was possible to immerse the cement under test at various depths, and thus to drive the liquid through the pores at more or less pressure, or an aspirator was employed to intensify the speed of filtration. A large number of cements and hydraulic limes were tested, and the results are set

forth in a table. It was found impossible, however, to obtain a uniform speed of flow, and to discriminate between the chemical action due to the various saline solutions and the mechanical action of filtration, and the Author concludes that no reliable results can be obtained by experiments of this nature.

G. R. R.

The Monumental Chimneys of the Paris Exhibition of 1900. A. DA CUNHA.

(La Nature, 31 March, 1900, p. 291.)

The whole of the motive power for the electrical section of the Paris Exhibition will be supplied from two groups of boiler houses situated behind the Palace of Electricity. Each set of boilers will furnish steam for motors aggregating about 40,000 HP., and it was decided that the two chimneys should be of a decorative character, 262 feet in height, 20 feet 4 inches internal diameter at the base and 14 feet 9 inches at the summit. A sum of £400 was offered in competition for the design, and the prize was awarded to Messrs. Nicou and Demarigny. The chimney, in accordance with the premiated design, has been erected on the side towards the Avenue de la Bourdonnais, and a chimney of similar dimensions, designed by the staff under Mr. Bourdon, has been erected on the Avenue Suffren side of the Exhibition. In each case there is a pedestal 62 feet in height, from which rises a circular shaft with a highly ornamental capping. The foundations needed special precautions, and each chimney rests on a circular bed of concrete 49 feet in diameter and 8 feet thick. This concrete is superimposed on 140 oak piles each 12 inches square and 23 feet long, driven down to a bed of compact gravel. Each chimney, which has needed three millions of bricks and weighs not less than 5,660 tons, is thus estimated to exert a pressure of about 4,600 lbs. on every square foot of the foundation, which is well within the limits of safety. By reference to diagrams an account is given of the methods of construction employed, which differ for each chimney, and afford a good means of comparing their respective advantages. An elevation of each chimney is appended.

G. R. R.

The Measurement of the Variations in Volume of Hydraulic Binding Materials. DEVAL.

(Bulletin de la Société d'Encouragement pour l'Industrie Nationale, January, 1900, p. 31.)

Many different methods have from time to time been proposed for measuring the increase in volume of hydraulic cements; some of them furnish very precise results and involve the use of special

apparatus. Among them are the plans employed by Messrs. Durand-Claye and Debray and by Mr. Bauschinger, which are here described. Others are of a more simple character, which, as they entail the employment of no special appliances, can be carried out upon the works. Among these latter are the method involving the use of measuring needles, due to Mr. Le Chatelier, the plan of using embedded pins, introduced by Mr. Klebe, and the mode of employing discs of dry compressed mortars, proposed by Messrs. Prussing and Le Chatelier. Each of these systems of testing is explained in detail. A large number of experiments, conducted in accordance with the three last-mentioned methods, are set forth in a tabulated form. The Author shows that the results obtained by the different methods vary somewhat widely, but are in the main such as would be anticipated from the character of the tests imposed. Certain of the figures are shown on graphic diagrams. A note is appended on the composition of the sulpho-aluminate of lime.

G. R. R.

Changes of Volume consequent upon the Induration of Cements. H. Le Chatelier.

(Bulletin de la Société d'Encouragement pour l'Industrie Nationale, January, 1900, p. 54.)

It is pointed out that some confusion exists on the subject of the changes which take place in the volume of cement mixtures, and this is due to the habitual neglect to distinguish between the apparent volume and the actual volume. The Author defines what is understood by these terms, and shows that the apparent volume must inevitably expand if the solid component parts are driven further asunder. The slaking of lime is accompanied by much increase in bulk and visible expansion, and small quantities of free lime in cements give rise to notable changes in the dimensions of the test-pieces. Good cements, free from lime, also expand slightly during the setting period, and it may be laid down as an invariable rule that all hydraulic cement mortars increase slightly in apparent volume during the period of induration. It has been generally deemed that this expansion was due to an increase in absolute volume, and that cement in combining with water increased slightly in bulk. The Author gives a series of tests, conducted with a large number of cementing agents, which in every case showed a diminution of absolute volume during the setting period and thus proved this conclusion to be erroneous. These tests were conducted in a species of large-scale thermometer-tube, that is to say, a glass bulb with a vertical tube. The reservoir had a capacity of about 70 cubic centimetres, and the tube had a bore of about 4 millimetres. In carrying out the experiments, about 10 grams to 50 grams of the hydraulic cement to be tested were made into a thin slip with 50 grams of water and rapidly introduced into the exhausted bulb. The contents were

then again exhausted of air, and enough water was added to bring the liquid about half-way up the vertical tube, which was then sealed at the top to prevent evaporation. Readings were subsequently taken of the water-level in the tube, which indicated the exact degrees of contraction successively taking place. It is stated as the result of these tests that all hydraulic binding agents manifest on hydration an increase in apparent volume, but a decrease in absolute volume. G. R. R.

The Strength of Blue Fir-wood. M. Rudeloff.

(Mittheilungen aus den königlichen technischen Versuchsanstalten zu Berlin, 1899, p. 209.)

The experiments described in a former Paper[1] were on specimens cut from trunks blown down by a storm in February 1894, or felled in March 1895, and allowed to lie in the forest until the beginning of the experiments September 1895. The experiments described in the present Paper were on specimens cut from trees specially felled for the purpose of the experiments. In September 1895, December 1895, March 1896 and June 1896, three trees were felled, and from each tree disks 10 inches thick were cut at heights of 1, 4, 8 and 12 metres from the ground, immediately after felling. In September 1896 disks were cut immediately above, and in April 1897 disks were cut immediately below those at 4 metres height. From each disk 6 specimens were cut.

The experiments on the compressive strength show that the strength of the air-dried wood diminishes as the height of the specimen in the trunk increases. The wood felled in December shows the greatest strength, that felled in September the least strength and density. The influence of the time of felling on the strength of the white wood diminishes with increasing height of the specimen in the trunk. The wood felled in September showed the greatest tendency to become blue, that felled in March and kept dry had little or no tendency to become blue. As regards seasoning, the compressive strength of all the specimens is diminished and the specific density is very slightly diminished by lying in the forest.

Splitting tests were made, from which it appears that the resistance to splitting diminishes with increasing height in the trunk. Lying in the forest diminishes the splitting strength, to a greater extent with white wood than with the blue. The splitting strength seems to be greater in the blue wood than in the white. The results are summarized thus—blue fir wood possesses greater compressive strength, greater density and smaller splitting strength than white wood. By lying in the forest, the compressive strength and splitting strengths of both blue and white wood suffer.

A. S.

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[1] Mittheilungen, 1897, p. 1, and Minutes of Proceedings Inst. C.E., vol. cxxx. p. 328.

Test to Destruction of a Swiss Railway Bridge. F. Schüle.

(Schweizerische Bauzeitung, 1900, p. 15.)

The bridge over the Erlenbach on the Schwarzwald Railway had been in use for thirty years, from 1866 to 1896, and as it was to be replaced by a new one it was decided to test it to destruction. The chief dimensions were:—length, 68 feet; height of girders, 4·92 feet; width between centres of main girders, 9·84 feet. Detailed views of the bridge are given, with dimensions. The Board of the Baden State Railway ordered the test, and it was therefore moved to a point 115 feet from its original position, and there supported upon special concrete blocks. The loads consisted of rails piled up on the cross-girders, and a stout wooden scaffolding was erected at each side of the bridge to support the load after breakage of the bridge.

On the 19th October the test was begun, and five evenly-spaced loads of 21·2 tons were put upon the bridge; three of these loads were then gradually increased until they were 21·2, 21·2, 45·7, 45·7, and 61·2 tons respectively. The deflection at each change of load was carefully taken, and is compared in a Table with the calculated deflections.

Views of the bridge after fracture are given. The side-girders are of the lattice type, and in the original article details are given as to the method of fracture; rivet-heads were first sheared, and the ultimate fracture was preceded by buckling of the lattice-work. The materials themselves were afterwards tested separately, and the general conclusion was that the bridge had been rightly superseded, as it was approaching a dangerous condition. The total cost of the test to destruction was £140.

E. R. D.

Bridge over the Spree. H. Müller-Breslau.

(Zeitschrift für Bauwesen, 1900, p. 65.)

This bridge is situated at a right-angled bend in the River Spree, and, as in such a situation it was very necessary not to hamper navigation, the centre one of the three spans into which the bridge is divided was increased from the length contemplated in an earlier design to 86 metres (282 feet) equal to half the total width of the river.

The floor of the bridge—3·5 metres (11 feet 6 inches) in width—is of timber, and rests on longitudinals and on cross-girders. These latter bear on the bottom flanges of the two outside main girders, which are of an entirely novel design. They may be described as made up of two simple structures, viz., (1) a continuous girder of three spans, having a hinge in the centre span

and three flanges for some distance on each side of the centre piers; (2) a straining arch over the centre span, the abutments of which are formed by the ends of the intermediate one of the three flanges mentioned in (1) where they meet the top flange.

This arch and the intermediate flanges form a continuous outline.

The central hinge in the continuous girder part of the structure consists of two parts: (*a*) a horizontal flat plate in the bottom flange, and (*b*) a joint in the top flange made with five bolts which take vertical stresses only, the holes being slotted to allow of relative horizontal movement.

The whole structure is twice statically indeterminate, the horizontal and vertical forces in the compound central hinge being taken as the unknown quantities.

The maximum stress in the metal of the bridge, assuming the platform loaded with 500 kilograms per square metre (102½ lbs. per square foot), is 1,200 kilograms per square centimetre (7·62 tons per square inch), and if in addition to the floor being loaded, a wind-pressure of 125 kilograms per square metre (25·6 lbs. per square foot) acts on the structure, the maximum stress becomes 1,400 kilograms per square centimetre (8·9 tons per square inch).

The total weight of steel was 157½ tons, amounting to about ½ cwt. per square foot, or 5½ cwts. per foot forward.

The total cost was 110,000 marks (£5,500), equal to 17*s.* per square foot, or nearly £10 per lineal foot.

W. B.

Power required to turn Swing-Bridges. R. Skutsch.

(Verhandlungen des Vereins zur Beförderung des Gewerbefleisses, 1899, p. 307.)

In this Paper the Author investigates the case of a bridge, turntable or other heavy mass requiring to be swung round within a given time. He assumes that the turning force is constant while the speed varies, and further supposes the time lost through the use of brakes towards the end of the motion to be a constant and ascertainable value.

He draws a time-speed curve, which, according to the assumptions above-mentioned, must consist of two portions: (1) a straight line inclined to both axes; (2) a line parallel to the time-axis. The junction of the two lines lies on a certain hyperbola.

The total force is put in the form—

$$F = p\,(\alpha + \beta),$$

where p is that force which would turn the bridge in the time allowed, acceleration continuing up to the moment of braking, and friction being left out of consideration; $p\alpha$ is the actual force used to produce the acceleration, and $p\beta$ the actual force used in overcoming the friction.

Working from the principles exhibited in his diagram, the Author obtains an equation corresponding to a minimum value of a.

No general solution of this equation is possible, but a Table is given, worked out for various values of the variables, which enables the necessary power of motor to be calculated.

A numerical example is added, showing the calculations to determine the HP. of a motor sufficient to turn a swing-bridge with arms of equal length of about 164 feet total length and 170 tons weight in 2½ minutes. The power to be developed comes to 1½ HP.

W. B.

Viaducts near Drum and Neuschloss on the North Bohemian Transversal Railway. H. Rosche.

(Zeitschrift des österreichischen Ingenieur- und Architekten-Vereines, 1899, p. 49.)

This branch railway extending from Teplitz to Reichenberg, is being constructed by the Aussig-Teplitz Railway Company. The section upon which these viaducts are situated is that between Leitmeritz, Auscha and Leipa. It is 42 kilometres (26 miles) long, and was opened for traffic 29th December, 1898. It forms an extension of the Teplitz, Lobositz, Leitmeritz section, 29 miles long, opened 18th October, 1898; consequently a length of 55 miles is completed out of the total of 92 miles. It may be mentioned that on 29th December, 1898, another branch line of this company was opened from Leipa to Niemes.

In the construction of the Leitmeritz, Auscha, Leipa section much difficulty arose from the unstable character of the ground passed through, necessitating heavy works in avoiding or dealing with slips. The most important of the works on the line are the above viaducts and a bridge over the Elbe at Lobositz, the latter described in No. 43, 1898, of the above journal.

The Drum Viaduct is 61 yards long and crosses the marshy valley of the Biberbach. It comprises four segmental arched openings each of 32 feet 10 inches span. The construction of an arched viaduct at this point, notwithstanding that the level of the rails is only 20 feet 4 inches above the ground-level, was for economical reasons. The foundations of the centre pier had to be carried down through morass and quicksand to a depth of 18 feet below the surface before reaching the sandstone rock, and in founding the fourth pier much difficulty arose from quicksand. The quantity of masonry in this work was 1,703 cubic yards, and the time occupied in its construction 7 months.

The Karba Viaduct is situated near Neuschloss; its length is about 273 yards, and height 79 feet. It is divided into two portions by a rocky promontory, dividing the Höllengrund Valley from the Helene Valley. The Höllengrund portion has a length

of about 172 yards with five openings, of which two, of 131 feet span, have girder superstructures, and three, of 39 feet 4 inches span, are arched; the Helene Valley portion, 103 yards long, has one opening of 131 feet span with girder superstructure, and two arched openings of 39 feet 4 inches span. The foundations of the piers etc. are carried down to a depth of from 2·0 metres to 4·2 metres (6 feet 6 inches to 13 feet 9 inches) below the ground-surface.

Particulars of the foundations are given. The quantity of masonry in this structure was 10,028 cubic yards. The open-hearth steelwork comprised parallel-flanged lattice girders 13 feet 7 inches deep, their transverse distance apart, centre to centre, being 9·10 feet. The quantity of metal in the three girder-spans is 288 tons. The Paper is illustrated by two photogravure views of the viaduct, a general plan of the district and a section of portion of the Drum Viaduct.

D. G.

The New Bridge over the Mulde between Niederschlema and Stein-Hartenstein (Saxony). P. Mehr.

(Zeitschrift für Architektur und Ingenieurwesen, 1899, p. 361.)

The Schwarzenberg-Zwickau State Railway was opened in May, 1858, and follows the narrow, winding steep-sided valleys of the Schwarzwasser and the Mulde. In some instances the curves were of only 170 metres ($8\frac{1}{2}$ chains) radius, and describing more than a semi-circle. The station at Niederschlema had been laid out in such a manner that with the increase in traffic it became imperative to deviate the line in the vicinity and at the same time improve the junction with the main line of the branch leaving at this point. It was determined to alter the course of the old line for a length extending over a distance of $3\frac{1}{3}$ miles from the station, adopting curves of a minimum radius of 15 chains, and preserving the old gradient of 1 in 100. An idea of the tortuous course of the old line may be formed from the fact that the length of the deviation was nearly 1 mile less in length than the section of line which it replaced.

The cost of construction of the deviation was of course much higher than was that of the original line, as it necessitated the construction of a tunnel 372 yards long, two bridges over the Mulde, two diversions of that river and heavy earthwork.

The new works included also the laying of a second track between the stations of Aue, Niederschlema and Stein-Hartenstein. The bridge, the subject of the Paper, is on a grade of 1 in 100 and crosses the river at a height of 46 feet, and the old line at a height of 27 feet 6 inches. The stream is 85 feet broad, varying in depth from a dry bed to a depth of 13 feet in time of flood, when large quantities of fallen trees, and timber from the saw-mills, are

brought down. On the left bank are a conduit and settling-tank in connection with a paper-mill, and these had also to be cleared by the bridge which is on the skew, angle 53°.

Careful consideration was given to the choice of the most suitable form of structure. Three designs for an iron superstructure were got out and were estimated to cost, with two spans of 123 feet and one of 160 feet 9 inches, £15,792; with two spans of 108 feet 3 inches and one of 144 feet 4 inches, £14,675; and with five spans varying from 92 feet to 73 feet 2 inches, £13,627; the cost of ironwork per ton being assumed at £17 10*s.*; whereas the estimate for a bridge entirely of masonry amounted to only £11,500, stone being plentiful in the vicinity, and it was decided to adopt this last form, the spans being one of 108 feet 3 inches for the stream opening, two of 46 feet on the left, and two of 46 feet and one of 36 feet (for the old railway) on the right bank. The maximum permissible pressure upon the foundation ground was fixed at 4½ tons per square foot, and the piers and abutments designed accordingly. The bridge carries a double line of normal gauge; it is 26 feet 11 inches broad, the parapets being corbelled out beyond this, and refuges for platelayers etc. provided over the piers. The total cube of concrete and masonry amounted to 8,319 cubic yards.

Particulars are given of the concrete and masonry, and the Paper is illustrated by a photogravure showing the bridge in course of construction and by a plate of diagrams.

The works were commenced in June 1898, and were to be finished Midsummer 1899.

D. G.

On the Flow of Water over Dams.

G. W. Rafter, M. Am. Soc. C.E.

(Proceedings of the American Society of Civil Engineers, March, 1900, p. 226.)

This valuable series of experiments on the discharge over weirs of various shapes was made to extend those of Mr. H. Bazin, Inspecteur Général des Ponts et Chaussées. The latter experiments applied to depths of rather less than 18 inches, whereas the experiments recorded by the Author apply to depths up to 6 feet. They were made at the Cornell University Hydraulic Laboratory,[1] for the United States Board of Engineers on Deep Waterways. The experiments give the value of C in the formula

$$Q = C\,H^{\frac{3}{2}},$$

where H includes the allowance made for velocity of approach. The values of C vary for different values of H for the same form of weir, and their variation for different shapes of weirs is considerable.

A. W. B.

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[1] Minutes of Proceedings Inst. C.E., vol. cxxx. p. 350.

Experiments on the Flow of Water in a 6-Foot Steel and Wood Pipe-Line (Second Series).

C. D. Marx, C. B. Wing and L. M. Hoskins.

(Proceedings of the American Society of Civil Engineers, 1900, p. 108.)

These experiments, made in June and July, 1899, are supplementary to those made by the Authors in August, 1897,[1] the main object, as before, being to determine the relation between the mean velocity of flow in the pipe and the loss of head between certain definite points. The methods employed varied very little from those in the previous experiments. The pressures were measured by mercury or water-gauges, and the rate of discharge was found by attaching difference gauges on the two Venturi meters.

The values of the coefficients in the Chezy and Kutter formulas are worked out.

Putting the formula in the form $v = c\sqrt{di}$, d being the diameter in feet, for the steel pipe, c varied from about 34 for a velocity of 0·5 foot per second to 51 for a velocity of 3 feet per second, after which it increased but slightly up to 5·5 feet per second.

In the case of the wooden pipe c was 60 for a velocity of 2 feet per second, and varied very little for velocities above or below this within the range of the experiments.

A. W. B.

Power of Explosive Projectiles to Ignite Timber.

(Morskoi Sbornik, February, 1900, p. 127.)

This is an account of some experiments made by the Swedish Government at the experimental battery at Karlskrona in 1899. The largest consisted of a timber shield about 20 inches thick, built up of the driest pine planks that could be procured, and faced with an iron plate $\frac{15}{32}$ inch thick. The shield was modified in details during the experiments to promote splintering and increase the chance of ignition. For the last experiment part of the shield was caulked like a ship's deck. Ordinary black powder was used for charging the projectile and firing. All the projectiles exploded within the timber of the shield.

One shot was fired from a 4·7-inch gun, then two from a 6-inch gun. Then ten shots were fired in rapid succession from a $2\frac{1}{4}$-inch quick-firing gun. In all these cases fine-grain powder had been used. Next three shots were fired from a 6-inch gun with 1·38-inch and 0·6-inch cube powder, partly whole and

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[1] Minutes of Proceedings Inst. C.E., vol. cxxxiv. p. 437.

partly broken up, for firing as well as for the projectile. In none of the experiments was there any sign of charring the wood, which only got blackened by the smoke; but after the last shot the tow of the caulking was found smoking and smouldering. It had been intended to experiment with "non-inflammable wood," but, after these experiments, that was not considered necessary.

It is considered, in conclusion, that the risk of ignition of timber by explosive projectiles has been greatly exaggerated, and that the fires which have so often occurred on vessels during engagements have, probably, always been started by the ignition of drapery, bedding, etc., which then set fire to the woodwork.

C. H. M.

Permanent Fortifications—Their Reduction and Defence.[1]

BARON VON LEITHNER.

(Mittheilungen über Gegenstände des Artillerie- und Genie-Wesens, 1899, p. 763.)

The Author remarks that the increased power of modern artillery necessitates a complete change in the method of attack and defence of fortifications, and proceeds to discuss the question in detail. As regards attack, the need of large numbers of technical troops, not only of garrison artillery and pioneers, but also of railway corps, is insisted on, together with the necessity of training them in all possible ways in peace time. A complete system of field railways, telegraphs and telephones is required for the rapid transport of guns and ammunition. The railways should, if possible, be worked by steam-power, and their proper organization and maintenance must be considered. For the Defence.—Transport and means of communication is also of great importance. The use of field railways is estimated to do away with 70 per cent. of the otherwise necessary draught animals. The importance of strict sanitary supervision is pointed out.

The long range of modern guns and the use of smokeless powder is in favour of an attacking force, as, if carefully placed, the position of their guns can only be located with great difficulty, while the permanent works of the besieged are of necessity visible.

W. B.

Hydraulic Brakes of Constant Resistance. PAUL SOCK.

(Mittheilungen über Gegenstände des Artillerie- und Genie-Wesens, 1899, p. 83.)

The Author considers in this Paper the construction of hydraulic brakes of constant resistance, in which one part of the apparatus —the piston or the cylinder—is fixed to an underframe, which is

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[1] Minutes of Proceedings Inst. C.E., vol. cxl. p. 372.

in turn rigidly connected with the ground, as is the case with guns of position, fortress and naval guns. Recoil brakes are dealt with first, and they are divided into two classes, according as the piston-rod is put into compression or tension at the instant of recoil. The brake has to be designed so that the energy represented by the explosion of the charge shall be taken up at a uniform rate by the resistance offered to acceleration on the part of the working fluid, frictional resistances, etc. It has been shown by experiment that the frictional resistances are sufficiently large to absorb a quantity of work at least equal to that required for acceleration of the water and sometimes 33 per cent. in excess of this.

Putting f = total area of passages in cylinder walls; v = velocity of piston, and c = a constant, the Author obtains the equation—

$$f = \frac{v}{c} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1.)$$

The next point is to determine how v varies with x, the distance of the piston from the commencement of the stroke.

Let v_r = maximum recoil speed, and x_r the distance the piston has passed through at the time the maximum speed is attained.

The value of v_r is given by an empirical formula; the value of x_r is made to depend, in the case of the tension brake, on the relative masses of the gun and projectile, and the length of barrel, and for the compression brake on the compression of the volume of air, which is of necessity at the upper end of the cylinder opposite to that occupied by the piston.

Putting the origin of co-ordinates at a distance x_r from the commencement of the stroke, the Author sets up the following equation:—

$$\frac{G}{g} v dv = -(Y + B + a_r + bx)\,dx \quad . \quad . \quad . \quad (2.)$$

where G = weight of gun, Y = pressure of brake, B = frictional and gravity resistance; $a_r + bx$ represents the effect of return springs to bring the gun again to a firing position.

From equation (2) and assuming the final velocity zero, the value of the brake pressure is—

$$Y = \frac{Gv_r^2}{2gx_o} - \left(B + a_r + \frac{b}{2}x_o\right) \quad . \quad . \quad . \quad . \quad (3.)$$

where x_o = stroke of piston $- x_r$.

Combining equations (2) and (1), and substituting the value of Y from (3), the Author obtains the law of variation of the area of the passages, which shows that the total area must vary with the distance from the end of the cylinder as the ordinates of a conic section, the particular curve depending on certain details of construction.

The Author next deals with brakes to control the action of a spring in bringing the gun forward into a firing position. The method of investigation is the same and the results are similar in form.

W. B.

Durability of Copper Alloys in Sea-Water. DIEGEL.

(Verhandlungen des Vereins zur Beförderung des Gewerbefleisses, 1899, p. 313.)

In order to determine whether the durability of various copper alloys in contact with other alloys and metals, in the presence of sea-water, could be foretold from their relative positions in the electromotive series, the Author carried out a number of tests in the following manner.

The bars to be tested were prepared of a shape similar to that of ordinary test bars, and, several being cut from one plate or casting, three of them were tested for strength and extensibility. The results of these tests formed a basis of comparison, the effect of the sea-water being judged from the lowering of strength and ductility in the bars which had been immersed. This method of estimating the depreciation was selected, because in very many cases the external appearance of a bar remains unaltered, although in reality its structure may have undergone considerable change, and also because the diminution in weight does not give a correct indication of the deterioration in strength.

The bars to be tested were riveted to plates of the different metals and hung in sea-water for periods varying from 8 months to 2 years. It was found that the bars suffered considerable injury only when they were in contact with an electro-negative metal, the destruction being more complete the greater the distance apart of the metals of the plate and bar in the series. Those bars endured best which were riveted to plates of metal that were high in the electromotive series. In fact, an electro-positive metal exercises a preserving influence on an electro-negative metal. This was proved in the experiments from the fact that those bars which had been riveted to iron plates or to metals of such composition as yellow metal, naval brass, etc., preserved their qualities much better than those in contact with any other metal. Pure aluminium bronze (91 copper to 9 aluminium) neither itself suffered a rapid destruction when in contact with an electro-negative metal, nor did it induce anything like so quick a deterioration of an electro-positive metal as copper or tin bronze, which proved themselves the most destructive of other metals in contact with them.

W. B.

On Micro-organisms in Fossil Fuel. B. Renault.

(Bulletin de la Société de l'Industrie Minérale, 1899, vol. xiii. p. 865.)

This is a long memoir upon the organisms contained in mineral fuels, peat, lignite, bituminous shale or cannel, and coal, founded upon observations continued for twenty-four years, which are illustrated by nearly 300 phototype illustrations. Starting from the study of peat, the Author finds that the chief agents of the transformation of the cellulose in the plants forming the peat-bogs are saprophyte fungi and bacterial ferments, the presence of air being essential for the activity of the former, while the latter are anaerobic, so that either cause may alternate with variation in the water-level of the bog. The destructive agency of bacteria seems to be limited by the production of ulmic acid, containing C 65·31, H 3·85, and O 30·83, which is a powerful antiseptic. The ratio of carbon to oxygen and hydrogen which are in cellulose $\frac{C}{H}=7\cdot 2$, and $\frac{C}{O}=0\cdot 9$, become in peat $\frac{C}{H}=9\cdot 8$ and $\frac{C}{O}=1\cdot 8$. In the different classes of lignite similar constituents, together with animal (infusorial) remains, are observed, the degraded product of the tissue forming a fundamental mass or paste, which was plastic at the time of formation, and has converted the more resisting elements of the plants into a compact mass. The average ratios are for perfect lignites, $\frac{C}{H}=12\cdot 6$; $\frac{C}{O}=3\cdot 6$; and for imperfect lignites $\frac{C}{H}=12\cdot 2$; $\frac{C}{O}=2\cdot 4$, showing that oxygen is less rapidly eliminated than hydrogen, the change being similar to that of peat, but more advanced. Bituminous shales, boghead, and cannel coals are mostly made up of gelatinous fresh-water algæ, transformed by an almost complete elimination of oxygen into a substance approximately of the composition C_2H_3, the ratios being $\frac{C}{H}=7\cdot 98$; $\frac{C}{O+N}=46\cdot 3$ for the boghead of Autun and Australia. The original boghead of Torbane Hill is nearly C_3H_5. In the cannel coals the prevailing vegetable constituents are the spores of cryptogamic plants, algæ being rare or entirely absent. In coal, owing to its opacity, it is more difficult to detect the presence of bacilli; but by making very thin sections, and especially in the wood of plants partially silicified, they may be found in considerable number; and one form, called Micrococcus Carbo, in many respects resembles the living Cladothryx of the peat bogs. The transformation of organic matter into coal is attended with considerable contraction, which may amount to between $\frac{11}{12}$ and $\frac{26}{30}$ of the original volume. Approximately the change may be expressed as follows:—

$$4\,(C_6H_{10}O_5)=C_9H_6\,O+7\,CH_4+8\,CO_2+4\,H_2O.$$

The solid product C_9H_6O representing the coal formed is about 20 per cent. of the weight of the original cellulose, the remaining 80 per cent. being eliminated as marsh gas, carbon dioxide, and water, under the influence of the different bacteria observed. H. B.

A New Extensometer. WILLIAM KENNERSON.

(Engineering News, New York, 25 January, 1900, p. 63.)

The specimen is placed vertically in the testing machine in the usual way, and the clamps are fixed at a predetermined distance. Of these the upper is attached by three set screws and the lower by two, one screw in each clamp being kept tight by a spring, thus obviating any slackening as the specimen stretches. The top clamp holds two micrometer screws, the spindles of which extend to the bottom one, where their ends rest in spherical cups. The pitch of the screws being $\frac{1}{40}$ inch and the periphery being divided into 250 equal parts, a reading of $\frac{1}{10000}$ inch is possible. The extensometer is provided with a drum, whose axis is parallel with that of the specimen, and with a cross-head carrying a pencil, and sliding in a direction parallel to the axis of the drum. The motion of the latter is proportional to the stretch of the specimen, while the rotation of the drum, being actuated by the travelling weight on the floating beam, is proportional to the stress. The stress is recorded in the following way. Upon the hub of each micrometer-screw is cut a helix of small angle. A cord is wound round this, the free end being attached to the recording cross-head, which is somewhat heavily weighted. The tension of the string tends to turn the micrometer in such a direction as to elongate it. Thus when extension of the specimen commences, the pressure upon the spherical ends of the micrometer screw-spindles is relieved; the weighted cross-head rotates the micrometer until normal resistance is restored. The motion of the cross-head, which is proportional to the stretch, has in the meantime been recorded by the pencil. Damage to the micrometer due to removal of the load before screwing the latter back is obviated by the spherical cavities in which they rest being provided with springs, which become compressed when subjected to undue pressure. A. P. H.

The Manufacture of Liquid Carbonic Acid.

(Engineering, 20 October, 1899, p. 505.)

Liquid carbonic acid is much used, both for experimental and industrial purposes. In the former it is useful as a refrigerant, and for obtaining a high pressure, whilst in the latter, aerated-

water makers are large customers. At the London Carbonic Acid Gas Works, Old Ford, the process of manufacture is as follows. Coke is burned under boilers, and the products of combustion, being mostly carbonic acid, are led to scrubbers containing potash-lye, by which it is absorbed. The lye is then passed into the boilers, where it is heated, and the carbonic acid given off, the latter being led to compressing pumps. The potash-lye is now passed back into the scrubbers to absorb a second charge of carbonic acid. The chief difficulty is the presence of sulphur dioxide in the products of combustion from the boiler gases. If this were allowed to reach the scrubbers, part of the potash-lye would be at once turned into potassium sulphate, and its property of absorbing carbonic acid would be destroyed. In many works much potash is lost by this means, but at the works in question a process of washing the products of combustion is resorted to. They are washed first with hot and then with cold water on their way from the boiler to the scrubbers, by which much potash-lye is saved. The compressing pumps are of the three-stage type, driven by belting. The first is double acting and compresses the gas to 20 lbs. per square inch, after which it is passed into a purifier, where any residual moisture is removed by calcium chloride. The second stage pump is single acting, and raises the pressure to 125 lbs. per square inch, after which the gas is passed into cooling coils before entering the final compressor. The latter is also single acting, and raises the pressure to 1,000 lbs. per square inch, which pressure, however, varies with the temperature. On account of this it has been found necessary to make an allowance for subsequently varying temperatures, and to fill the bottles used for transportation only to about two-thirds their full capacity.

A. P. H.

A Mode of Constructing Wrought-iron Drums, so as to Avoid Accidents in Transport. Claussen.

(Annalen für Gewerbe und Bauwesen, 15 January, 1900, p. 33.)

It is pointed out that metal drums are now largely used for the transport of aniline, ammonia benzine, concentrated sulphuric acid, etc., and special attention is directed to the employment of such vessels for acids, since leakages may not only cause serious injury to workpeople who may have to handle the drums, but they may also lead to conflagrations on board ships, and thus occasion total loss. By reference to diagrams, a description is given of a drum capable of containing 66 gallons and weighing, when empty, about 189·5 lbs. It consists of a cylindrical case of sheet iron 0·098 inch in thickness, with the ends formed of plates 0·157 inch thick, electrically welded on. The drum has four hoops, the two inner ones being H-shaped in section, so as to form rolling-rings, and serving also to protect the projecting bung-hole. The ends, in

lieu of being flat, are dished inwards, and by this means provision is made for the expansion of the contents; for if internal pressure takes place the ends are forced outwards to a corresponding degree of curvature. The Author states that the extra room provided by such expansion is sufficient in the case of sulphuric acid, which may expand to about 2·4 per cent. of the volume. Some photographic representations are given of drums which have been exposed to internal pressures up to 6¼ atmospheres, showing the bulged ends caused by the internal pressure. It is stated that when these drums were submitted to test, one end began to spring outwards at a pressure of about 5 atmospheres, and then the manometer fell back to from 2½ atmospheres to 3 atmospheres; on continuing the pumping the pressure remained steady for some time until the end had become fully expanded outwards, then the pressure again rose, till at about 5 atmospheres the other end began to bulge, and when 6¼ atmospheres was reached the electric welding of the ends began to tear away and the contents leaked out. By reference to diagrams a full account is given of the nature of the joint effected by the welding, and the formula is indicated for calculating the strength of the welded joint. It is suggested that during the welding process some change takes place in the quality of the metal, and the Author explains how a much stronger joint can be obtained by simple riveting.

G. R. R.

Mode of Working of the Coherer. RICCARDO MALAGOLI.[1]

(Il Nuovo Cimento, October, 1899, pp. 279–282.)

In addition to the sparking which takes place between the metal filings in the working of the coherer, Tommasina has shown that a conducting chain is formed by some of the filings becoming welded together under the heating action of the sparks. The formation of the chain can be observed by placing the coherer upright, and slowly drawing the electrodes further apart while the electric waves are passing. A single chain is all that ever forms; less than one second is required for its formation, and the action of the waves appears to be progressive; the less readily the metal of the filings oxidizes, the more readily do they set up the chain. If, instead of putting the electric waves into action, a secondary induction-coil be attached direct to the coherer, the arrangement of the filings into "self-forming" chains, as they are called by Arons, takes place on a much larger scale, even without initial contact of the filings with the two electrodes. With a Ruhmkorff coil capable of giving sparks 35 centimetres (14 inches) long, chains are seen to start up and race with rapid jumps to reach their goal;

[1] Minutes of Proceedings Inst. C.E., vol. cxxxvii. pp. 528-9, and vol. cxxxviii. p. 560.

in less than a second a series of sparks crackle between the two electrodes, the chain then forms, and instantly the remainder of the particles come to rest. Instead of the metal filings, the Author tried substituting brass chips from a lathe, which were turned off as slender and pointed as possible. In his experiment these were deposited on a metal disk in the bottom of a cup containing petroleum or vaseline oil, in which was also immersed a little ball; to both disk and ball were attached wires leading out of the cup, either of which was earthed, and the other connected with a weak electrostatic machine. If the ball is far enough from the disk, it discharges itself by convection, alternately attracting and repelling the chips, as in the old experiment called the "electric dance." A galvanometer with cell in series, having one terminal connected with the disk wire and the other with the ball wire, shows that the circuit remains open during the discharge. On diminishing the distance between disk and ball to about 2 centimetres (0·8 inch), the initial convective motion of the whole mass of chips on starting the electric machine is succeeded by a spark between ball and disk, and a row of chips become soldered into a chain; the rest fall back on the disk, and the galvanometer undergoes a violent permanent deflection. The metal chain equalizes the potential between ball and disk, so that the electric field is obliterated in the liquid; no other inductive action can exert motive power upon the chips, and there remains only the single chain by itself. The fusibility of the metal plays a more important part than the facility with which it oxidizes. Iron chips also form the chain readily, while iron filings in water were found by Tommasina to cohere very slightly or not at all. The time the chain takes to form depends upon how soon the chips happen to get into such a position as will allow a spark to pass, with the potential difference employed; it diminishes as the difference of potential increases, and as the distance between the electrodes diminishes. It also depends on the size of the chips; with filings in general, particularly the finest, it is rarely possible to observe the formation of the chain, unless the electrodes are near enough to each other.

A liquid having high insulating resistance and little viscosity, like petroleum, is much better for demonstrating these phenomena than distilled water, which was almost exclusively used by Tommasina, who found that with drinking water, or water slightly acidulated, the formation of the chain could not be seen; the conductivity prevented the electric field from acquiring even at the outset any appreciable value. In air the chain has great difficulty in forming, because the discharging action of the points of the filings is sufficient to overcome the insulating power of the air. The whole of these conditions have been confirmed by experiments with an induction coil. The electrodes of the coherer appear to have a highly important office, as it is in them that the electric waves, cut by lines of magnetic force appreciably differing in phase, produce a rise of potential, whilst the filings are so close together

that the difference of potential between them will be extremely small. Finding that the resistance of powdered metals is reduced by the vibrations of a tuning-fork placed on the table, Auerbach attempted a mechanical theory of the working of the coherer; but Calzecchi, who had also observed the same fact, considered it was due to the powder being thus rendered more compact, just as it would be if compressed. The Author concludes that Lodge's ideas respecting the mode of action of the electric waves upon powdered metals, which led him to choose the name "coherer," are completely in accordance with reality.

A. B.

Magnetic Action for Decohering. T. TOMMASINA.[1]

(Il Nuovo Cimento, October, 1899, p. 283. Comptes Rendus, vol. cxxviii. p. 1225.)

The most sensitive Marconi coherers contain nickel filings with a trace of silver filings; excellent results are also obtained with filings of cobalt, iron, and steel. When a magnet is brought near the coherer, the filings are attracted either in mass or in portions, and the conductivity disappears immediately. Instead therefore of resorting to shaking the coherer, its sensitiveness may be automatically restored by holding it horizontally, placing an electro-magnet a few tenths of an inch beneath it, and inserting in the coherer circuit an accumulator, a resistance, and the relay for opening and closing the magnet circuit. When these appliances have once been adjusted, the receiving of signals is perfect, with tubes containing iron, cobalt, and nickel filings. The movement of the filings is visible, and remarkably precise. For regularity of working, an important improvement is thus realised for wireless telegraphy.

A. B.

Three Methods for Measuring Minute Elongations. GUIDO ERCOLINI.

(Il Nuovo Cimento, October, 1899, pp. 241 and 251.)

Having occasion in some of his researches to measure extremely small displacements, the Author devised three methods: the first is based upon the principle of the Wheatstone bridge, and requires the use of a galvanometer; the second depends upon the fall of potential produced by a great resistance, and requires the use of an electrometer; the third and simplest does not require any

[1] Minutes of Proceedings Inst. C.E., vol. cxxxvii. pp. 528-9; and vol. cxxxviii. p. 560.

special instrument. None of the three, so far as he knows, has hitherto been applied to the measurement of minute elongations.

First method.—The principle of the Wheatstone slide-wire bridge was employed by the Author at the outset by using a liquid resistance to form the two arms leading to the ends of the bridge proper or galvanometer circuit; the point whose minute displacement is to be measured is rigidly connected with one terminal of the battery circuit, which dips into the liquid resistance; the two arms beyond the ends of the galvanometer wire are ordinary resistance coils, whose outer extremities are joined by a long straight metallic wire, along which slides the other terminal of the battery circuit. Any minute displacement of the first terminal has therefore to be balanced by shifting the sliding terminal along the junction wire through a distance which magnifies the minute displacement in proportion as the resistance of the long junction wire is less than the liquid resistance. In the Author's application of this principle, the two arms leading to the Wheatstone bridge consist of a solution of sulphate of zinc contained in a vessel of about 240 cubic centimetres (14 cubic inches) capacity, in which are immersed three electrodes of pure amalgamated zinc. The two nearest the ends of the galvanometer bridge are little cylinders of about 2 millimetres (0·08 inch) diameter, inside glass tubes; the middle electrode, of which the displacement is to be measured, is a disk about 4 millimetres (0·16 inch) diameter. The galvanometer with an internal resistance of 130 ohms is so sensitive that, when the resistances and lengths of the four arms of the bridge are suitably proportioned, a displacement of 1 millimetre (0·04 inch) in the sliding contact on the junction wire causes the ray of light reflected from the galvanometer mirror to move through one small division upon a scale 2·3 metres ($7\frac{1}{2}$ feet) distant from the mirror. While calculating that by this means an elongation of no more than 0·0000001 millimetre (1–250,000,000th of an inch) can be rendered perceptible, the Author speaks of 0·00001 millimetre (1–2,500,000th of an inch) as a high degree of sensitiveness in the apparatus.

Second method.—A narrow shallow glass trough, 1 millimetre (0·04 inch) wide, contains a solution of sulphate of zinc with 5 per cent. salt, 1 millimetre (0·04 inch) deep. Two slabs of amalgamated zinc at the ends of the trough are connected with the poles of a battery of forty small accumulators, sending a current through the solution, into which dip three electrodes of amalgamated zinc, *a b c*, spaced about equidistant. The middle electrode *b* is movable by means of a micrometer screw; and the object desired is, as before, to measure its minute displacement between *a* and *c*, which are fixed. Six mercury cups are arranged in two rows, 1-3-5 facing 2-4-6; the two middle cups 3 and 4 communicate with the two plates of a Hankel gold-leaf electrometer, in which the leaf is kept at a constant positive potential by a dry cell. But with a view to combining the least possible capacity with the greatest sensitiveness, the Author substituted for the

gold leaf a single thread of cocoon silk, which he rendered conducting by painting it over with common commercial purple or sulphide (*sic*) of tin[1] mixed with gum; this is attached to the electrometer by a drop of the mixture, and retains its conductivity unimpaired for many days, being protected from moisture by placing a beaker of sulphuric acid inside the electrometer. A german-silver measuring wire of about 1 square millimetre (0·0016 square inch) section, stretched horizontally through a length of 3 metres (10 feet), is placed in an earthed circuit with three Daniell cells, from which the current is regulated by resistance coils. The electrode *a* communicates with cup 1, *c* with cup 6, and the movable electrode *b* through cup 2 with the near end of the german-silver measuring wire; from cup 5 starts the wire which forms the sliding contact with the measuring wire. When the two middle cups 3 and 4 are connected with 1 and 2 respectively, the electrometer thread shows a certain deflection, due to the difference of potential between the electrodes *a* and *b*; and in order to produce the same deflection when these connections are broken and cups 3 and 4 are joined to 5 and 6 respectively, and when the sliding wire is at the near end of the measuring wire, the fall of potential from *b* to *c* must be equal to that from *a* to *b*. Confirming his calculation, the Author's trials showed that, when by means of the micrometer screw the middle electrode was moved towards either side through 0·01 millimetre (0·0004 inch or 1–2,500th of an inch), the slide-wire contact had to be shifted through 10·15 centimetres (4 inches) along the measuring wire, being a magnification of ten thousand times; and this method will measure an elongation down to 0·0001 millimetre (1–250,000th of an inch).

Third method.—A silk thread 40 centimetres (16 inches) long and doubled in the middle, formed of three or four single cocoon threads, has its ends secured alongside each other 1 millimetre (0·04 inch) apart in an overhead clamp hung from a micrometer screw. The loop 20 centimetres (8 inches) long is threaded through a hole 1 millimetre (0·04 inch) diameter in the centre of a narrow strip of mica 10 centimetres (4 inches) long, and is stretched tight by a screwed hook at bottom, thus forming two vertical threads of equal tension. The mica strip is fixed with wax in the middle of their length, and is adjusted to be truly horizontal. Just above the bottom hook the two threads are brought together by being bound round with a silk knot. On its ends the mica strip carries two little cylindrical iron armatures, attracted in opposite directions by two permanent magnets, which are placed symmetrically in the same horizontal plane as the armatures, and thus form a couple tending to rotate the mica strip. The angle of rotation is observed by the ray of light from a mirror carried on the centre of the strip. The minutest lowering of the overhead clamp relaxes

[1] Presumably *chloride* of tin is meant, because it is from a dilute solution of a mixture of the two tin *chlorides* that the "purple of cassius" is obtained by the addition of gold trichloride.—A. B.

the tension upon the threads, and enables the magnets to rotate the mica strip according to the degree of relaxation. On a scale 2 metres (6½ feet) from the mirror, the lowering of the top clamp through 0·01 millimetre (0·0004 inch or 1–2,500th of an inch) swings the ray of light through a distance easily subdivided into fifty parts, while with greater care four times this deflection may be obtained: so that as little as 0·005 millimetre (1–5,000th of an inch) can be rendered clearly perceptible.

In a footnote the Author recalls three other methods which he considers highly sensitive. (A) A spring of thin steel ribbon coiled into a cylindrical helix, as employed in the Ayrton and Perry ammeter and low-potential hot-wire voltmeter. (B) Two pulleys of large and small diameter, rotating in the same vertical plane, are geared together by a thread, kept taut by a weight. On the axis of the smaller pulley is fixed a radial mirror; and the extremity of the rod, of which the elongation is to be measured, bears against a short arm on the axis of the larger. Thus the elongation is magnified, firstly in the ratio of the larger pulley's radius to the leverage at which the rod acts; secondly in the ratio of the larger pulley's radius to that of the smaller; and thirdly in the ratio which the length of the beam of light reflected from the mirror bears to the smaller pulley's radius. (C) A large Marey capsule communicates through a tube with a smaller capsule, which carries a mirror facing a scale. The disk of the larger capsule undergoes the displacement to be measured, which is magnified in proportion to the relative areas of the capsules and to the length of the beam of light from the mirror.

A. B.

Alternators for Electrical Research. GUIDO ERCOLINI.

(Il Nuovo Cimento, October, 1899, p. 243.)

In electrical researches in which the Author has occasion to employ the Wheatstone bridge in conjunction with a liquid resistance, the use of the latter involves sources of error from variations of temperature and from polarization. The former may be guarded against by employing a vessel containing a large quantity of liquid; and also by keeping the circuit closed for as short a time as possible, whereby polarization also is diminished. As a further precaution against polarization, a weak and alternating current is derived from electrodes of amalgamated zinc immersed in a solution of sulphate of zinc, which has been neutralized with carbonate of zinc and boiled for a length of time while the electrodes are immersed in it. Having tried unsuccessfully to get an alternating current by combining a Ruhmkorff coil with a telephone, the Author reverted to a cell in combination with a suitable alternator for sending an alternating current through the liquid resistance, while at the same time so arranging that through the galvanometer the current should

pass in one direction only. For this purpose he constructed six simple alternators, all of which gave him good results.

1. A wire, fixed at the ends and passing half round a vertical tightening pulley, has its two spans stretched horizontally one above the other in the same vertical plane; midway in each span is a small soft iron armature, which carries beneath it an insulated pair of forks dipping into and out of two pairs of mercury cups; above the upper armature is one electro-magnet, and beneath the lower another. Both magnets are simultaneously excited by a cell, whose current passes through a pair of mercury cups into which dips an insulated fork projecting beneath the lower armature: so that the current is interrupted by the vertical vibrations of the span carrying this armature. From another cell, which sends the current to the Wheatstone bridge, alternative circuits are arranged for it to pass through the pair of forks carried by the upper or by the lower armature respectively, according as the electro-magnets are inert or excited. The galvanometer circuit is closed by one only of the two armatures.

2. Agreeably with Sauveur's experiment,[1] a cord stretched horizontally has its ends fixed, and in the middle of its length a knife-edge support just touches its underside. In the middle of one half-length is a small soft-iron armature over an electro-magnet, through which passes a current, interrupted as in No. 1 by the vibration of the cord itself; in the middle of the other half-length is a weight equal to the armature. When the cord vibrates vertically, the central knife-edge determines a stationary node, and the vibrations of the two halves are in opposite directions to each other, thus alternately closing one circuit and opening the other.

3. Applying Professor Bongiovanni's experiments[2] on the longitudinal vibrations of a helical coil, a cylindrical helix is used of such a length as to produce a node midway when it vibrates; the two halves then vibrating in opposite directions serve thereby to alternate a current.

4. A vertical helix, fixed to a support in the middle of its height, is made of wire stiff enough for its upper half to stand upright; each end carries a small armature facing an electro-magnet, and the action is the same as in No. 1 alternator.

5. Two equal helical coils, connected in series at top, hang side by side with their lower ends dipping into mercury cups in the circuit of a cell; one end remaining permanently submerged, the current is interrupted only whenever the other end emerges. If their lower ends carry insulated metallic forks, the latter can alternate the current to the Wheatstone bridge, much in the same way as in No. 1, provided the oscillations are ample enough.

6. On the basis of Melde's experiments,[3] a fine string attached to

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[1] Mémoires de l'Académie des Sciences, 1701; and Roiti's "Elements of Physics," vol. i. p. 319, fourth edition.

[2] Academy of Medical and Natural Science, Ferrara, 24 March, 1898.

[3] Poggendorfs Annalen, 1860, p. 193; and Roiti's "Elements of Physics," vol. i. p. 326, fourth edition.

an upright prong of an electric tuning-fork is stretched horizontally to such a length that its vibration produces a single node midway; in the middle of each half-length are three forks of fine wire, dipping into and out of mercury cups beneath. With this alternator great regularity of working is obtained, and vibrations of 2 centimetres (¾ inch) amplitude or more; while further the number of vibrations can readily be varied and determined exactly. For these reasons the Author has adopted it in his experiments. The alternations of the current in the circuit are produced as before by two of the three forks on each side of the node; the third fork on one side sends the current through the galvanometer, and the third on the other side through a resistance equal to that of the galvanometer: so that the current through the liquid resistance at the Wheatstone bridge is of equal strength in both directions. For obviating the influence of induction, the fork controlling the galvanometer circuit is made a trifle shorter than the others, so as to close its circuit after they have closed theirs, and to open it again before them.

A. B.

Goldschmidt's Rail-welding Process. GOLDSCHMIDT and BEYER.

(Street Railway Journal, February, 1900, pp. 158–159.)

This process permits the rapid production of molten iron in a crucible without a cupola. Powdered aluminium is mixed with powdered oxide of iron and is ignited, when the latter supplies the excess of oxygen necessary to support the combustion of aluminium, which forms liquid aluminium oxide, or "corundum," and reduces the iron oxide to molten iron. A sheet-iron mould is placed around the joint to be welded, and is packed with stones and sand. The mixed powder of aluminium, &c., is ignited by a special fuse, consisting of a small ball of superoxide of barium and aluminium, which is itself ignited by burning magnesium ribbon. The aluminium oxide rises to the top of the crucible, and when poured enters the mould first, forming a thin protecting coating on the sheet iron and sides of the rail. A layer of corundum also forms on the inside of the crucible as a fireproof glaze, which preserves the heat of the molten metal to such an extent that the workmen can handle the crucible without trouble.

Beyer added to the above description given by Dr. Goldschmidt to the Verein Deutscher Strassen und Kleinbahn Verwaltungen, some notes on the effect of temperature on cast-welded joints. He experimented on a 7-inch girder rail, having a cross-section of 52 square centimetres, and a tensile strength of 6,000 kilograms per square centimetre. The modulus of elasticity which would theoretically double the length of an iron rod 1 square centimetre in section, is 2,000,000 kilogram-centimetres. Therefore, for a range of 60° Celsius, which he considers the maximum in Germany

the force, considering iron to expand 0·1079 per cent. for each 100° Celsius, is 67,330 kilograms, so that the factor of safety in this case is 4·6. He claims that the temperature of the welding may be so chosen that the ends of the rails are not actually melted, thus preventing any change in the structure of the material. E. H. C.-H.

Burgdorf-Thun Three-Phase Electric Railway. C. Rochat.

(Street Rly. Journ., December, 1899, pp. 853–860.)

The line is 40 kilometres in length, and at Burgdorf connects with the standard steam road between Berne and Olten, whilst at Thun it runs in connection with the Berne-Thun Interlaken Railroad. In order to make close connection with each of these lines a larger train service was necessary than would have been convenient with steam power; and again, the grades, though not very steep, would yet have been considerable for steam-operated trains. With electricity, on the other hand, the grades are easily surmounted. Single cars can be run frequently; and by means of three-phase transmission at high voltage, advantage can be taken of a water-power at Spies about 10 kilometres from Thun.

Power Station.—Four turbines, located on the Kander River, operate under a fall of 63 metres, with an average volume of 10,000 litres of water per second, equal to 6,300 HP. Each generator has a capacity of 900 HP. and produces three-phase current at 4,000 volts, which is raised to 16,000 volts in step-up oil-transformers. The lighting is kept distinct from the power circuit.

Track.—The line is single track throughout, the maximum gradient 2½ per cent., and the minimum curve-radius 250 metres. The rails, 36 kilograms, are in 12-metre lengths, and the complete track weighs 110 kilograms per metre. The rails are bonded by having the under side of head and top of base grooved and filled with zinc, as are also the angle plates bearing upon these parts. Cross connections are made at 100-metre intervals by 8-millimetre wires.

High-tension Line.—The pole line for the 15,000-volt transmission consists of three copper wires, each 5 millimetres in diameter, carried on porcelain double-petticoat insulators. Between Spies and Thun the wires are carried on latticed poles set in concrete, but along the track the poles are of wood, the maximum span being thirty-five metres. There are Siemens-Halske horn lightning arresters at the entrance to the power station and at each substation, and to avoid short circuits to earth after atmospheric discharges water rheostats are introduced in the earth connection.

Substations.—There are fourteen transformer substations, each containing a 450-kilowatt oil-transformer, having a ratio of 15,000

volts to 750 volts. The transformers and switchgear, &c., are enclosed in metal housings, surmounted by the overhead construction for the high-tension wires.

Trolley Wires.—These are two in number, 8 millimetres in diameter, carried 5·1 metres above the track, and 1·1 metre apart. Double insulation is employed between trolley wires and poles, the latter spaced 35 metres apart except at curves. The bow sliding trolley is used, and there are no overhead frogs except at turnouts. At those points where the wires cross, section insulators are installed, and as the cars carry four trolleys, two at each end, contact with at least one set is always secured.

Electric Locomotives.—These are two in number, of the following dimensions: Wheel base 3 metres, length of body 6 metres, length between buffers 7·2 metres, diameter of wheels 1·3 metre, and weight complete 28 tons. They are employed principally for freight traffic, and are capable of hauling 100 tons (freight) at a speed of 18 kilometres per hour on 2½ per cent. grade, or 50 tons (passengers) at 36 kilometres per hour. Each locomotive is equipped with two motors of 150 HP. running three hundred revolutions per minute at 750 volts. They are placed in the middle of the locomotive, and at either end of the same shaft, the stators being mounted on the locomotive framework.

The rotor shaft can be thrown into gear with either of two trains of gears (for the two speeds) connected with the axles. For facilitating the mounting and dismounting of the rotors, the sides of the locomotives have openings through which the shaft can be removed.

The starting rheostat is composed of helical coils of ribbon separated into three sections corresponding to the three phases and connected to a commutator fitted with carbon brushes. At each end of the locomotive are two switches, one for making and breaking the circuit, and the other for reversing.

Each locomotive carries a transformer for reducing the pressure from 750 volts to 100 volts. Part of this low-tension current is used for operating a motor compressor of 3 HP. for the air brake, and part for lighting.

Motor-Cars.—At present there are six motor-cars, each capable of carrying sixty-eight passengers, the weight of the car fully equipped being 32 tons. The following are the leading dimensions: Length of body 12·2 metres, width of body 3·05 metres, distance between centres of trucks 9·5 metres, wheel base 2·2 metres, diameter of wheels 1·02 metre, and length over all 16·3 metres. Four 55-HP. motors are carried on each car (one to each axle), and they run at 600 revolutions per minute with load, and 586 without. The starting rheostat is similar to that on the locomotive, as is also the motor compressor, &c.

Trail Cars.—There are five trail cars of the two-axle type—two to carry each fifty-five passengers, two to carry each forty passengers, and one combination passenger, postal, and baggage-car carrying 20 passengers.

Running.—As the cars are operated by three-phase, a practically constant speed of 36 kilometres per hour is maintained. The cars can be braked quickly and stop in about three-quarters of a minute; a table of tests made on the 2½ per cent. grade is given. Tests of the power consumption at starting gave the following results:—

(*a*) One motor and one trail car on 2½ per cent. grade straight track, 260 amperes at 760 volts.

(*b*) Same as above, but on curve 250 metre radius, 330 amperes at 850 volts.

(*c*) The maximum consumption of the electric locomotive with a complete train of 50 tons at 36 kilometres per hour never exceeded 300 amperes at 700 volts.

It has been found not advisable to run two trains of cars at the same time in a section fed by one transformer. With two trains they should be six minutes apart, and with three trains the headway is ten minutes. (The article is abundantly illustrated.[1])

E. K. S.

Advantages of Superheating and the Superheater of Liége University. G. Duchesne.

(American Electrician, February, 1900, pp. 75–76.)

A few authentic cases are cited of the increased economy due to superheating, and a description of the Liége superheater is given, together with the results of some tests showing a saving due to superheating of 11·25 per cent. on an installation not designed to obtain economy.

J. T. R.

Tests of a Westinghouse Gas Engine. C. H. Robertson.

(Engineering, vol. lxix. pp.135–140. Paper read before the American Society of Mechanical Engineers.)

The Author gives (1) a description with drawings of a 125-H.P. Westinghouse gas engine, using natural gas and driving a 60-kilowatt two-phase alternator; and (2) results of a five hours' test, under service conditions, with measurements of the power developed and gas consumed, at Lafayette, Ind., in March, 1899. The three vertical cylinders, 13 inches diameter by 14 inches stroke, have a clearance of 21·28 and 21·59 per cent. The gas and air pass through a mixing-valve chamber, and the speed is controlled by throttling the charge. To start the engine, compressed air is stored in a steel cylinder at 160 lbs. gauge pressure. One cylinder is converted into a compressed-air engine until speed is got up to slightly compress and fire a charge in the other cylinders by electric igniters.

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[1] *Ante*, p. 16.

A gasoline vapour generator is installed to provide against interruption of the gas supply.

Chemical analysis of the natural gas used as fuel gave the percentage of methane 92, hydrogen 0·6, hydrocarbon 0·5, and carbon monoxide 0·55, with carbon dioxide 1·8, nitrogen 3·8, and oxygen 0·7. The exhaust pipe was red hot, and its temperature by copper ball calorimeter was about 1,200° F. "Back-firing," or ignition of the incoming charge in the distribution pipe, took place during the test. The highest speed in revolutions per minute was 280, the lowest 265, and the average 270·86; or a variation of 5·5 per cent. The average I.H.P. was calculated from observation every five minutes. The efficiency of the alternator was known, and hence the B.H.P. of the engine. The highest mechanical efficiency was 84·6 per cent.

The tests showed the lowest and highest gas-consumption in cubic feet per hour (reduced to 14·7 lbs. per square inch and 62° F.) to be 11·87 to 18·42 per I.H.P., 14·71 to 29·65 per B.H.P., and 16·52 to 40·59 per electrical H.P. By plotting the total gas per hour and the different I.H.P.'s in each case, a straight line can be drawn to represent the average gas-consumption at different loads, like Willans' law for steam engines, namely, that the total steam per hour plotted against the I.H.P. is a straight line.

The conclusions are: (1) That the proportion of gas to air is a very important factor in fuel economy; (2) that one test at a light and one at a heavy load would give the line, from which a prediction could be made of the gas-consumption under intermediate loads; (3) these hold for the fuel consumption per B.H.P.-hour and per electrical H.P.-hour. The best thermal efficiency of the engine, that is, the B.Th.U. equivalent to the B.H.P. divided by the B.Th.U. in the gas consumed, was 17·3 per cent.—not high for a gas engine. The heat distribution is shown by the following Table:—

Time.	B.Th.U. supplied per Hour.	Per Cent. converted into indicated Work.	Per Cent. absorbed by Jacket.	Per Cent. lost by Exhaust.	B.Th.U. per I.H.P. per Minute.
First hour	1,574,200	17·9	25·2	56·9	237·5
Second „	1,674,880	16·3	21·0	62·8	264·7
Third „	1,169,000	20·7	30·2	48·9	294·2
Fourth „	1,096,600	20·2	36·9	42·7	211·1
Fifth „	828,000	16·0	50·3	43·9	259·3

The poor result during the first and second hour is due to the improper mixture of gas to air in the proportion of 1 : 11, then the ratio was changed to 1 : 12. The lowest consumption of gas per I.H.P. per hour was 11·87 cubic feet, giving 11,870 B.Th.U. at a cost of $0·07 (3½*d.*) per thousand cubic feet.

The main results and features of the trial are shown graphically.

W. R.

Liverpool Trials of Motor Vehicles; Judges' Report.

(Automotor Journal, January, 1900, pp. 143–153.)

This is an abstract of the report of the trials made at and near Liverpool in October, 1899, of six different heavy motor vehicles

TABLE I.

Summary of Particulars.	Thornycroft No. 1.	Thornycroft No. 2.	Coulthard No. 3.	Leyland No. 4.	Clarkson and Capel No. 5.	Bayley No. 6.
Total moving weight laden and fully provisioned, including attendants—tons .	7·465	8·420 3·182	4·998	7·753	6·765	7·282
Mean moving weight laden and fully provisioned, including attendants—tons .	7·235	8·094 3·182	4·886	7·636	6·676	7·129
Mean tare, not including attendants —tons	3·582	4·004 0·737	2·524	3·141	3·359	3·469
Load carried—tons .	3·73	4·09 2·56	2·32	4·44.	3·35	3·67
Ratio of mean tare to load	0·96	0·71	1·09	0·71	1·00	0·95
Declared B.H.P.. .	35	40	14	14	14	22
Mean tare per declared B.H.P.—cwt.	2·04	2·37	3·60	4·48	4·80	3·16
Mean total moving weight per declared B.H.P.—cwt. . .	4·14	5·46	6·98	10·88	9·54	6·48

TABLE II.—SUMMARY OF FACTORS AFFECTING THE COSTS PER NET TON-MILE.

Vehicle.	Prime Cost.	Load carried.	Commercial Speed.	Fuel Consumption per Vehicle-Mile.	Fuel Consumption per Ton-Mile of Load.	Water Consumption per Vehicle-Mile.	Water Consumption per Ton-Mile of Load.	Cost of Motive Power per Ton-Mile of Load.	Cost of Attendants per Ton-Mile of Load.
	£	Tons.	Miles per Hour.			Gallons.	Gallons.	d.	d.
Thornycroft	590	3·73	5·31	8·88 lbs. coal	2·38 lbs. coal	7·15	1·88	0·27	0·44
Thornycroft	640	6·65	5·67	12·46 lbs. coal	1·87 lbs. coal	9·81	1·33	0·22	0·36
Coulthard.	400	2·32	4·78	..	..	..	..	..	..
Leyland .	450	4·44	5·02	0·539 gall. oil	0·121 gall. oil	4·00	0·91	0·62[1]	0·38
Clarkson .	450	3·35	4·94	0·724 gall. oil	0·216 gall. oil	2·13	0·64	1·09	0·52
Bayley .	600	3·67	4·93	6·76 lbs. coke	1·84 lbs. coke	4·65	1·27	0·13	0·65

[1] Last year's cost was 0·53*d.*, kerosene being then at 4*d.* per gallon. If kerosene had been at 5*d.* per gallon as it is now, the cost for last year would have been 0·66*d.*

under the auspices of the Liverpool branch of the Automobile Club of Great Britain. There were entered for the trials eleven vehicles, and of these the six whose makers' names are given in the accompanying Table I appeared and went through the trials. This Table is an abstract of the whole of the most important results, obtained during tests which included the transport of heavy loads over various good and very bad roads and hills, and over considerable distances. Table II gives a summary of those figures which relate to cost per ton-mile of goods carried. The Tables together provide information which is a key to the whole report, all the vehicles being steam propelled.

W. W. B.

Bromilow's Magnetic Separator for Workshops.

P. CHEVILLARD.

(L'Éclairage Électrique, vol. xxii., 1900, pp. 177–179. Revue Industrielle, vol. xxxi., 1900, p. 4. Engineer, vol. lxxxviii., 1899, p. 550.)

The machine described in this Paper is specially designed for the separation of particles of steel and iron from those of copper, brass, &c., in the refuse turnings and borings from engineering works. The method adopted consists in passing the mixed metal particles from a hopper into a conical shell lying with its axis horizontal. Inside are a number of electromagnets revolving on a spindle and arranged to push the contents forward in the direction of the base of the cone. The magnets, after passing through a certain angle, are demagnetised by the current being automatically cut off, and allow the adhering iron and steel to drop off into a receiver below through a cavity in the casing. A fixed brush assists this clearing action. The non-magnetizable metals travel forward and are discharged at the end into a separate receiver.

The machine will treat 2 tons per diem. It revolves at 30 revolutions per minute and requires a current of 21 amperes and 7 volts. It weighs about 3 cwt. and requires only about 1 HP. for revolving and supplying the current. There are drawings in section and perspective illustrating the mechanism.

J. L. F. V.

Balanced Piston-valve. W. O'BRIEN.

(Mechanical Engineer, February 24, 1900, pp. 256–257.)
Paper read before the Institution of Engineers and Ship-builders in Scotland, January 23, 1900.

A comparison is made between an engine of the usual four-crank type, having two piston-valves and two flat slide-valves for the four cylinders, and an engine fitted with cylinders of the same dimensions, having only two Clyde balanced piston-valves and two

sets of valve gear for the four cylinders. The latter engine is 5 feet 3 inches shorter over all. With the abolition of portions of the valve-gearing and pipe connections the weight of the engine is considerably less. The combined high-pressure and intermediate-pressure valve has five ports; the top and bottom ports take the boiler steam into the high-pressure cylinder through straight ports at the top and bottom of the cylinder. The exhaust steam from this cylinder passes through the top and bottom ends of the valve into the interior of the valve, and from there it passes through the ports on each side of the middle or exhaust port into the intermediate-pressure cylinder. The exhaust from the intermediate pressure cylinder passes into the middle port of the valve, then into the receiver or connecting pipe to the valve for the two low-pressure cylinders. The low-pressure piston-valve has only three ports.

A. S.

Molas Lamielle and Tessier Compressed-air Delivery-wagon Motor. P. Guédon.

(Automotor Journal, February, March, 1900, pp. 238 *et seq.* From "La Locomotion Automobile.")

After a brief description of previous work, this article explains the main features of an air-engine-propelled vehicle, in which it is claimed that by using batteries of thin tubes the inventors are able to carry air at a pressure of 290 atmospheres with a weight of vessel of 4·5 times the weight of air. The air reservoirs are divided into two groups—one of six, the other of eleven—containing together about 500 litres, or at the pressure named, 178 kilograms, the reservoirs weighing altogether 775 kilograms. On its way to the motor the air passes through a steel-coil tube 7 millimetres in diameter, 3·5 millimetres thick, and 6 metres in length, heated by a mineral-spirit burner, raising its temperature to about 150° C. by the consumption of about 500 grams, or 1·1 lb. of spirit. The air next passes through a pressure regulator reducing valve, on leaving which it has to be again heated by means of a coil similar to the first. The motor has four single-acting cylinders in two pairs, with pistons connected to cranks at 180°, the cranks of one pair being placed at 90° to those of the other. The pistons are fitted with cup leathers, and the exhaust valves are of the mushroom type, the admission valves being small rods with conical ends sitting in coned seats. The valves are worked by a rocking lever at the back of the engine, which receives its motion from cam-operated slotted links, one for giving full movement to the valves and the other for varying the point of cut-off. This arrangement is illustrated. The outlines of results of trials dated the 2nd of October, give weight of vehicle empty as 360 kilograms; load carried, 10 persons; distance traversed,

8 kilometres = 4·96 miles; time occupied, 1 hour 20 minutes; average speed, 6 kilometres, or 3·72 miles per hour; pressure of air at starting, 136 kilograms; at end of journey, 55 kilograms; fall in pressure, 81 kilograms, corresponding to a weight of 48 kilograms of compressed air, or 6 kilograms per kilometre, or per ton-kilometre 1·3 kilograms. The cost of air compression is not given.

W. W. B.

Accidents to Water-tube Boilers and their Remedies.

A. Ravier.

(Écl. Électr., December 16, 1899, pp. 427–429. Paper read before the Assoc. Française, at Boulogne.)

The causes of accidents to water-tube boilers have been classified according to the following table, from statistics collected (in France) for the years 1890–1897. In this Table E indicates that the cause was exclusive, and C that it was combined with some other cause.

	E.	C.
I. Splitting of the tubes:—		
1. From formation of scale in the tubes	8	9
2. „ abnormal fall of the water-level	12	1
3. „ worn-out tubes	4	2
4. „ defective manufacture	3	3
5. „ muddy deposits due to bad circulation	5	1
6. „ forcing the boiler	2	4
Total of accidents from known causes	34	20[1]
7. From unknown causes	8	
II. Other accidents	11	

Out of seventy-three accidents, fifty-two were due to rupture of the tubes, and in the case of forty-eight of these the exact positions of the tubes in the boilers were as follows:—

Tubes in the bottom rows	17
„ second and third rows from the bottom	6
„ intermediate rows	18
„ top rows	7
Total	48

To prevent scale, the only sure method is to have pure water; otherwise an active circulation must be maintained in the tubes immediately over the fire (which tubes should not be less than 2 inches in diameter); the feed should be delivered in the steam space, all grease should be separated from the condensed steam, and the boiler should be frequently cleaned.

[1] Ten of these with rupture of the tubes.

The boiler may be emptied for cleaning either when hot and under steam pressure or when nearly cold. The first method is the more rapid, but frequently causes hard deposits, which must be removed by hammer and chisel at the risk of damage to the boiler. The second, though slower, gives rise to muddy deposits which are easily washed out, and therefore it is recommended.

Attentive supervision is the remedy for lowering of the water-level, and the wear of the tubes can be greatly prevented by having them made of nickel steel, containing 25 per cent. of nickel.

In order to confine the effects of ruptured tubes to the smallest possible limits, an automatic tube stopper has been designed by A. Janet for horizontal tubes, which remains at an angle permitting the proper action of circulation in the boiler as long as the currents are flowing in the normal directions, but is quickly forced up into the mouth of the tube when there is a rush of water towards a leak. The pressure in the boiler then holds the stopper in position, and the escape of water and steam is prevented.

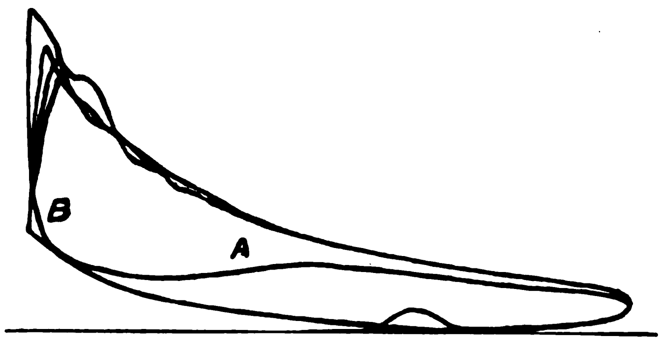
F. J. R.

Gas Engines. J. Dunlop.

(Mech. Eng., November 18, pp. 739–742; November 25, 1899, pp. 766–768.)

This Paper, read before the Owens College Engineering Society on the 14th November, 1899, gives the results of an investigation of the troubles experienced with a large gas engine of the high-speed single-acting type, working on the common four-stroke, or "Beau de Rochas," cycle. The usual positions of the crank are shown when the valves are timed to open and close; also the valve-setting of the Crossley scavenging engine, by which it was attempted to utilize the wave action of the exhaust for clearing the burnt products out of the cylinder. Here the air and exhaust valves were open together during the latter part of the exhaust stroke and the early part of the suction stroke, until the exhaust valve was closed later than usual. The economy effected was found to be almost entirely due to an increase in the compression pressure of the engine, and not to the "scavenging." A Crossley scavenging engine cylinder, 18½ inches in diameter by 24 inches stroke, was required to develop at 200 revolutions per minute a maximum of 102 B.HP. for two hours on Dowson gas. To do this it was necessary to maintain, during every possible power-stroke, a mean pressure of 75 lbs. per square inch. The engine had only been running a few minutes on trial when explosions in the air pipe began to take place alternately with bumping noises in the cylinder. Indicator diagrams, as shown in the Figure, were taken to locate these troubles. The small loop above the atmospheric line is the indication of an explosion in the air pipe during the

suction stroke. Consequently during the next power-stroke A, the charge of burnt gases only smoulders instead of burning quickly. Light spring diagrams show that the explosions in the air pipe took place at all parts of the suction stroke, and that, owing to the exhaust valve being open during part of the suction stroke, a portion of the hot smouldering exhaust products was drawn into the cylinder. This would also account for pre-ignition, indicated at B, which produces the knocking in the cylinder. In the case of an engine having an ignition timing valve, this pre-ignition is mostly caused by overheated metal in the cylinder igniting the charge of air and gas under compression. After the engine had been running twenty minutes, explosions in the air pipe and pre-ignition became almost continuous, and, with the ordinary ignition apparatus out of action, continued for a time to ignite the charges automatically. Although the load was eased, the engine



pulled up at the end of about half an hour, when the exhaust valve was seen to be a dull red heat, and small pieces of wood laid on the top of the valve took fire immediately. This was remedied by making the exhaust valve hollow for cold-air circulation in the interior of the valve. The writer's contention is that in this scavenging engine the valve-setting was the cause of nearly all the trouble.

When a run was made with the normal valve-setting, the engine acted quite satisfactorily, The mean pressure throughout the stroke was 85 lbs. per square inch with coal gas. A simple and reliable scavenging arrangement, like that in the Premier gas engine, is desirable, especially for engines using Dowson or similar fuel gas.

W. R.

Gas-Engine Guarantees. W. T. MAGRUDER.

(Indus. and Iron, December 22, 1899, pp. 411–412.)

[Abstract of Paper presented at the First Annual Meeting of the National Association of Gas and Gasoline Engine Manufacturers of the United States.]

Power.—Some gas-engine catalogues fail to distinguish between nominal, indicated, and actual horse-powers. The variation in indicator diagrams, from a gas engine having either a throttling or hit-and-miss governor and a load which varies, prevents greater accuracy than 90 per cent. to 95 per cent. in the measurement of the indicated HP. The continuous indicator is not yet a practical success.

The friction of the engine may use up 10 per cent. to 35 per cent. of the work done on the piston. The chief value of the ordinary gas-engine indicator is to show faulty setting of valves, excessive back pressure of exhaust, and obstruction in gas and air inlets. Engines should be sold by the actual power delivered at the belt pulley or crank-shaft, which can be easily measured by a brake.

The accurate regulation of speed of gas engines is necessitated by the effects on electric lamps, and the fluctuation is reduced by the kinetic energy of heavy fly-wheels. Guarantees are given in catalogues of gas-engine makers of the variation of speed being only 1 per cent. and 1½ per cent., while one claims to run his engine at "an absolutely uniform speed, which may be varied instantly from 50 revolutions to 600 revolutions per minute;" but the writer has never seen any steam engine which regulated as badly as some gas engines.

It is essential in making guarantees as to cost of running not only to know the cost per cubic foot of gas or per gallon of oil, but also the calorific value of that fuel per cubic foot, per lb. or per gallon, at standard temperature and pressure, knowing the specific gravity, as well as other physical properties of the fuel.

Consumption of fuel will vary with the calorific value, and the best proportion of air; also with the size of air valves, passages, and pipes. Other things being equal, the volume of gas used will vary with the pressure and temperature of both the gas and air. A gas engine should be guaranteed to give a HP. on a given number of heat units with a given fuel. The day has passed when gas-engine guarantees can be made, accepted, and paid for, on "so many feet of gas per HP.," and nothing more.

W. R.

High-Furnace Gases for Power. B. Donkin.

(Engineer, November 24, pp. 509–510; December 8, pp. 561–562; December 15, 1899, pp. 588–590.)

These articles give a description and general plans of some large gas engines adapted to use high-furnace gases. The Oechelhaueser gas engine, with two pistons working in opposite directions in one cylinder, is similar to the Atkinson "Differential." At the Hörde Ironworks in Westphalia a 600-HP. Oechelhaueser motor, made by the Deutsche-Kraft Gesellschaft, consists of two single-cylinder engines, each of 300 HP. at 135 revolutions per minute. Each cylinder is 19 inches diameter, and 31·5 inches stroke with pistons. A 1,000-HP. engine of this type, with two cylinders and four pistons, is being erected at Fishershütte, near Hanover.

The Simplex engine of Delamare-Deboutteville and Malandin to work with high-furnace gas, is made by the Société Cockerill, at Seraing, in Belgium.[1] In December, 1895, a 4-HP. experimental engine was started with these waste gases, and was improved to develop 8 HP. A 200-HP. single-cylinder simplex engine was built in 1897, and tested by Witz on a 24-hours' run with blast-furnace gases in July, 1898. The cylinder was 31·5 inches diameter, stroke 3·28 feet, and at 105 revolutions per minute gave 181 B.HP. (French), with mechanical efficiency 85 per cent. The mean consumption was 117·5 cubic feet per B.HP.-hour, and the calorific value of the gas was 110 B.T.U. per cubic foot. The gases are induced from the top of the furnaces by a Koerting steam-jet, and further washed in scrubbers to remove part of the dust; and the charge is compressed in the engine cylinder to 8 atmospheres before ignition by electric spark. Two or three grammes of metallic dust per cubic metre of gas are carried into the cylinder and pass out with the exhaust, equal to 88 lbs. daily for the 200-HP. engine, which has been working satisfactorily for 18 months. Four simplex engines, each of 550 B.HP., having single cylinder of diameter 4 feet 3 inches, stroke 4 feet 7 inches, with Riedler valves, are being constructed to drive the blowers direct.

In Germany the Gas Motoren Fabrik, Deutz, make ordinary Otto cycle engines of two cylinders, on opposite sides of crank, up to about 250 B.HP. per cylinder; thus a 500-HP. plant has two and 1,000 HP. four cylinders. At Oberhausen the furnace gases are cleaned by passing through three coke scrubbers and four purifiers with small coke, but no water is used. In October, 1898, Meyer tested a 60-HP. Otto motor driven with high-furnace gas.[2] The engine indicated 79·5 HP., and the B.HP. was 65·3 with a consumption of 96·7 cubic feet of gas B.HP.-hour. The heating value of the gas in the calorimeter was 105 B.T.U. per cubic foot, and the heat turned into indicated work 30·2 per cent. These

[1] Revue Universelle des Mines, vol. xliii., 3rd series, p. 113, 1898.
[2] Zeitschrift des Vereines deutscher Ingenieure, vol. xliii. p. 453.

results are better than those obtained in ordinary practice. In England the work done hitherto with high-furnace gases has been chiefly experimental. At the Glasgow Ironworks, Wishaw, a 30-HP. Acme gas engine started in 1895, and the consumption is 95 cubic feet of high-furnace gas per B.HP.-hour. The furnace is fed with Scotch splint coal, and the waste gases have a heating value of 98 B.T.U. per cubic foot. The engine, tested by Booth while driving a dynamo, gave 1 E.HP.-hour per 1½ lb. of coal fed into the furnace, and consumed about 140 cubic feet of gas per E.HP.-hour. A plant of 160 HP. has been working at Barrow-in-Furness.

Plans are given of a 530-HP. two-cylinder motor, built by Crossley for producer gas; also of a 250-B.HP. Stockport gas engine to work with coke-oven gas; and of a Premier single-cylinder gas engine of 250 B.HP., the first large power engine built to utilize high-furnace gases in England.[1]

W. R.

Modern Mine-Haulage Practice. H. K. Myers.

(Proceedings of the Eng. Club, Phil., 1899, pp. 221 *et seq.*)

This Paper deals with the applications of locomotive power to haulage in mines, describing steam locomotives, compressed-air locomotives and lastly electric locomotives. Some striking figures as to the mileage of underground haulage ways and haulage miles per annum in some mines are given. It is estimated in the United States there are 50,000 miles of mine track utilizing 100,000 mules, whose average life is only four years, the haulage costing 15 cents (7½*d.*) per ton-mile. Descriptions of the various locomotives and their performance are given, among others of electric locomotives by the Balmin-Westinghouse Co., by the General Electric Co., and others. One of these machines in practice is found to replace 24 mules and 12 men, saving $8,000 (£1,600) per annum.

Ll. B. A.

Specific Resistance of Nickel. J. A. Fleming.

(Proceedings of the Royal Society, March 3, 1900, pp. 50–58.)

Mathiessen's determinations of the specific resistances of various metals made in 1860 to 1865 are usually shown to be correct within very narrow limits by more recent experiments. For nickel his value of 12,320 C.G.S. units at 0° C. is usually assumed. Recently the Author has made a special investigation of the specific

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[1] Science Abstracts 1900, No. 297; also 1898, Nos. 991, 992, and 993.

resistance at temperatures ranging from − 182° to + 95° C. of a nickel wire 250 centimetres long and 0·02567 centimetre in diameter prepared electrolytically from a purified solution of nickelous chloride and annealed in hydrogen. The results are tabulated and plotted as a curve which tends as usual to pass through zero at the absolute zero of temperature. The specific resistance thus determined is only 6,935 C.G.S. units at 0° C., and the mean temperature variation is 0·00618 between 0° C. and 100° C. The discrepancy is probably due to some impurity in Mathiessen's specimens.

L. B.

Colours of Heated Steel corresponding to Different Degrees of Temperature. M. White and F. W. Taylor.

(Indus. and Iron, December 15, 1899, p. 398. Paper read before the American Society of Mechanical Engineers.)

Estimations of the temperature of heated steel by the eye vary considerably with different observers and with the quality or intensity of the light in which the observations are made, but from a number of experiments with the Le Chatelier pyrometer the following colour scale is considered as best suited to the conditions met with in most workshops. The temperatures are given in degrees Fahrenheit. Dark blood red, black red, 900°; dark red, blood red, low red, 1,050°; dark cherry red, 1,175°; medium cherry red, 1,250°; full cherry red, 1,375°; light cherry, bright cherry, scaling heat, light red, 1,550°; salmon, orange, free scaling heat, 1,650°; light salmon, light orange, 1,725°; yellow, 1,825°; light yellow, 1,975°; white, 2,200°.

N. L.

Electro-deposition of Zinc. S. Cowper-Coles.

(Electrician, January 19, 1900, p. 434.)

The experiments described by the Author were undertaken in order to determine the adhesiveness of zinc to steel, when deposited under varying conditions as regards preparation of the steel plates, acidity of the electrolyte, and current strength. It was found that perfect adhesion was only secured when the current was reversed for a few moments before commencing the deposition. In other cases the deposit was non-adhesive, a result ascribed by the Author to the slight film of oxide which covered the steel. Neutral solutions were found to yield the most regular and even deposits.

J. B. C. K.

Steam Turbines and High-speed Navigation. C. A. Parsons.

(Nature, March 1, 1900, pp. 424–428.)

Paper read before the Royal Institution, January 26, 1900.

The Author traces the history of the earliest records of the steam engine down to the latest Laval steam turbine. In 1884 the first Parsons turbine engine of 10 HP., and running at 18,000 revolutions, was made, and is now on view in the South Kensington Museum. As steam was admitted in the centre of the turbines and worked its way out over the guide blades and vanes towards either end, there was no end pressure or thrust on the bearings, and the shaft was free to revolve with a minimum amount of friction. The speed of these small turbines was extremely high. In 1888 several 120-HP. non-condensing parallel-flow turbine engines were made and run at much lower speeds. In 1892 the first large radial-flow condensing turbine was constructed for 200 HP. at 4,800 revolutions, driving a 150-kilowatts alternator. Its consumption was 27 lbs. per kilowatt-hour, or say 16 lbs. per I.HP.-hour. The latest turbo-alternator of 1,200 kilowatts with 130 lbs. steam, 10° C. superheat, gave 18·8 lbs. per kilowatt-hour, which is equivalent to 11·9 lbs. per I.HP.-hour, and compares favourably with the best reciprocating steam engines.

The most important field for the turbo-motor is that of high-speed navigation, and the "Turbinia" was the first boat built. Great difficulty was experienced from what is known as "cavitation," on account of the extremely high speed of the shaft driving the propellers. Elaborate experiments were carried out to investigate this phenomenon, and led to the deduction that for fast speeds, wide thin blades, coarse pitch ratio, and moderate slip are best suited to prevent cavitation. The one original shaft of the "Turbinia" was now changed for three separate shafts, each carrying three propellers, one behind the other, and 32¾ knots was now reached on the measured mile and a consumption of 14½ lbs. per I HP. hour. A special turbine was fitted to one of the shafts for going astern. In 1898 the Admiralty ordered a 31-knot destroyer called the "Viper." She has four independent screw shafts with two propellers on each shaft. The boilers are of the Yarrow type, with 15,000 square feet H.S. and 272 square feet G.S. The mean speed reached on the preliminary trials was 34·8 knots, the highest run being 35·5 knots with 11,000 HP., as compared with 6,000 HP. to 6,500 HP. of the ordinary 30-knot destroyers. The designs for cross-channel and other classes of steamers are also briefly dealt with.

L. S. R.

Water-tube Boilers in the U.S. Navy. G. W. Melville.

(Mech. Eng., December 16, 1899, pp. 897-899. Abstract of Paper read before the Society of Naval Architects and Marine Engineers, New York, November, 1899.)

The adoption of water-tube boilers in all future vessels of the U.S. Navy is a natural step in the advance towards a perfect naval fighting machine. The engineer-in-chief of that navy considers that the design of these boilers is wrong in principle on account of the pressure being inside, instead of on the outside, of the tubes, these being the weakest part of the boilers; also on account of the smaller quantity of water in the boiler, the difficulty of observing a leak, and the decreased value of the heating surface. Nevertheless these boilers are tactical necessities for warships. They are considerably lighter than boilers of the old type, and in consequence the ship having them will be smaller and handier—will have somewhat less draught, and will cost less. The draught of water is the limiting condition in size of warships, so that for a maximum of fighting efficiency water-tube boilers must be used. Any saving of weight or space consistent with efficiency is of great importance in war vessels.

All torpedo boats and destroyers in the American navy since the "Cushing" have been equipped with water-tube boilers, which have proved to be quite as reliable as the light engines used in these boats, and by making the attainment of higher speeds possible have added to their efficiency and security.

The water-tube boilers in the "Monterey," the "Nashville," the "Marietta," the "Annapolis," and the "Chicago," of different designs, have come successfully through a number of trials—the "Monterey" having made a voyage of about 8,000 knots, largely under forced combustion, and whenever possible with all boilers in use, and the "Marietta" having made a trip round South America, with marked success in the performance of these boilers.

The re-tubing of these boilers has been accomplished on board by the engineering staff of the vessel, without the necessity of laying up the ship at a navy yard, and the parts of new boilers have been assembled and erected in position without disturbing the decks. In the case of vessels having protective decks, the latter is a result of enormous importance, and one impossible with cylindrical boilers.

Particular attention must be given to the feed arrangements with water-tube boilers—the feed pumps must be ample and the regulation easy. The heating surface, which was at first 3 square feet per HP., as against 2 square feet, necessary with cylindrical boilers, is now 2·4 square feet. The ratio of heating to grate surface is kept up to 40, the grates being larger than those of cylindrical boilers. The increased grate surface obtained with water-tube boilers is an improvement, giving power of sustained sea speed. No trouble has been experienced from salt water or grease in these boilers, but in the short naval war with Spain the

United States war-vessels suffered severely from dropped furnaces in cylindrical boilers. With regard to the accidents and failures reported against water-tube boilers, the Author remarks that we hear of all the failures, but the successes are never mentioned. He considers that the experience of the last ten years or more in the United States and other navies proves that water-tube boilers, when proper precautions are used, can be successfully adopted for the steam-generating plant of ocean-going vessels. A number of warships are being fitted with water-tube boilers. The Paper concludes with a summary of the advantages and disadvantages of these boilers which have been discussed.

F. J. R.

Dust-destructors and Electric Supply. LAURIOL.

(Soc. Int. Elect., Bull., 1899, pp. 468–484.)

A detailed estimate of the economy in an electric supply station by the use of dust destructors as a source of energy. The results are worked out for three calorific values of refuse, viz., for 50 kilowatt-hours per ton as in the case of London refuse, for 20 kilowatt-hours as determined in Paris, and for 5 kilowatt-hours, a minimum value. Four conditions of running are considered: (1) When the refuse is burnt and the power supplied uniformly, taking the cost of coal at a halfpenny per unit, there is a saving of 2*s*., 9*d*., and 2*d*. per ton respectively for the three classes of refuse. (2) When the refuse is burnt uniformly and the peak of the load taken by coal firing there results a saving of 0·1*d*. to 11*d*. per ton of refuse. (3) When the refuse is burnt as required to supply the load, unless the load factor is very high, the heavy outlay in destructor furnaces required to take the peak results in a loss as compared with coal firing. (4) When accumulators are employed to make the load factor of the plant 100 per cent., a saving of from 1*d*. to 2*s*. per ton of refuse is possible.

L. B.

Cost of Arc Lighting. H. H. WAIT.

(Trans. American Institute of Electrical Engineers, November, 1899, pp. 579–604.)

Tables are given in this Paper showing the comparative first cost and operating expenses of various arc-lighting systems, on an equitable basis. The Author refers to a recent article by W. L. Robb[1] on the Hartford system of arc lighting, where it was stated that the changes in the Hartford plant would pay for themselves in about two years. From the Tables in the present article,

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[1] Science Abstracts 1900, No. 955.

it would appear that in some cases the more modern continuous-current systems might replace older ones and pay for the changes in still less than two years. The question is so dependent on local conditions, however, that it is impossible to make any general statements.

The vital question in comparing alternating and direct-current systems, is the relative amount of power consumed for the same amount of light. In compiling the Tables, the different types of lamps have been given the following ratings for the sake of comparison :—

	Candle-power.
Direct-current open arc—450 watts at arc	2,000
" " enclosed arc—450 watts at arc	1,500
Alternate-current enclosed arc—450 watts at arc . . .	1,150
" " " " 400 " " . . .	950
Direct-current open arc—300 watts at arc	1,200
" " enclosed arc—300 watts at arc	900

To arrive at an equitable figure for comparing the direct-current open and enclosed arcs, it was assumed that the ratio of watts per mean spherical candle-power in the open arc to those in the enclosed arc, is 75 per cent. The figure is practically a mean of the results obtained by Elihu Thomson, L. B. Marks, Pierron, and W. O. Steel. It was further assumed that the excess of watts per mean spherical candle-power for alternate-current over direct-current arcs is $33\frac{1}{3}$, which is practically a mean of the results obtained by Matthews, L. B. Marks, Elihu Thomson, W. O. Steel, and the Western Electric Co. In the Table of costs, the resulting costs have been divided by the nominal candle-powers, so that the cost can be compared readily at any reasonable rating. The Tables are all made on the assumption that the arc lighting part of the plant is running at very nearly full load whenever it does run. This will, of course, not apply to commercial lighting circuits, and considerable corrections will have to be made for such conditions.

A point in favour of the alternating systems is the fact that the position of the plant or other local conditions may permit a saving in the line investment; for example, where a large number of circuits have to be run for a long distance in the same street, a saving in the investment could probably be made by the alternating system by the use of a substation at the point of distribution. In cases where there is already a greater generator capacity installed than is actually needed, it is, of course, possible to leave out a considerable portion of the investment shown in the Tables. In rare cases, the peak of the commercial lighting and power load would not overlap the arc-lighting load, and under such circumstances, some of the transformer systems, either direct or alternating current, would have a great advantage.

Curves are given in this Paper showing the luminous intensity at street surface with different lamps. In general, it will be seen that the direct-current plants are the most favourable for places

where the whole or nearly all the output is used for arc lighting—where but a small portion of the load is arc lighting—either the simple alternating systems or some of the systems transforming into direct continuous current by means of motor generators or rectifiers would be most practicable.

COMPARATIVE COST PER ARC-LAMP PER YEAR OF 3,800 HOURS WITH DIFFERENT SYSTEMS.

No.	System.	Total cost per lamp in $.	I.HP. per Lamp.	Total Operating Expenses in $.
1	Hartford, 400 watts enclosed	146·50	0·744	52·86
2	Hartford, 450 " "	155·24	0·822	57·85
3	Alternate-current Ind. Reg., 400 watts enclosed	139·80	0·708	50·75
4	Direct-current arc driven by alternate-current motors, 300 watts enclosed . .	131·42	0·630	46·03
5	Direct-current belted, 300 watts enclosed .	117·90	0 552	41·75
6	" " arc, driven by direct-current motors, 300 watts enclosed	129·45	0·642	46·06
7	Direct-current arc belted, 450 watts enclosed	147·37	0·830	57·07
8	Direct-current arc belted, 450 watts open arc	142·60	0·832	68·53
9	Direct-current arc direct driven, 450 watts open direct current	142·00	0·810	62·58
10	Alternate-current Ind. Reg., 450 watts enclosed. No increase in generating plant	91·14	0·804	45·89
11	Direct-current arc driven by alternate-current motors, 450 watts enclosed. No increase in generating plant	100·40	0·948	53·93
12	Rectifier system, 450 watts enclosed . .	154·30	0·816	53·69
13	Glow, 3–50 candle-power lamps, 450 watts .	121·75	0·766	60·85

L. J. S.

Electrolysis of Water Mains. L. I. BLAKE.

(Elect. World and Engineer, December 16, 1899, pp. 934–935.)

Owing to the greater resistance of the joints compared to the pipe itself, water mains cannot be regarded as uniform conductors. If connected to the return of an electric tramway a portion of the current is shunted at the joint by the water inside and outside the pipe, causing electrolytic corrosion. Numerous tests of pipe lengths are given, showing that from 80 to 90 per cent. of the resistance occurs in the joints, the pipes being pitted inside and outside on the positive side of the joint to a depth in some cases of $\frac{1}{4}$ inch.

L. B.

Traction Accumulator Trials. A. BAINVILLE.

(Électricien, 1899, pp. 398–400.)

The French Automobile Club trials are summarized as follows:—

Number.	Names of Competitors.	Total Weight.	Total Output.
		Kilograms.	Watt-hours.
1 F	Société anonyme pour le travail électrique des métaux. Paris	104	764
2 L	Compagnie générale électrique. Nancy. "Pollak" plates	119·5	795
3 K	Société Tudor. Paris, Brussels, and London	125·7	1,358
8 Q	Lagarde. Paris	89	363
9 E	Wuste et Rupprecht. Vienna	70·25	145
11 N	Société de l'accumulateur Fulmen. Clichy	76·5	1,022
13 I	" " " "	83	318
17 P	Société des soudières électrolytiques. Gavet-Clavaux (Isère)	77·5	446
18 J	Franz-Heimel. Vienna	59·5	360
19 M	W. Pope and Son. Slough. "Sherrin" plates	86·3	375

M. O'G.

Electrical Heating.

(Electrical Review, 1899, pp. 954 *et seq.*)

Electrical heating for certain purposes is undoubtedly expensive and extravagant, but there are many purposes also to which it can be applied where electricity will be found cheaper than other methods. The points to be considered, when comparing electric heaters with others, are given. The everyday uses to which electrical heating can be applied with advantage are considered, such as: (1) Flat-irons for laundry purposes; (2) rolls for laundry work; (3) goffering-iron heaters for laundries, dye-works, &c.; (4) hot-plates and glue-pots for wood-workers' shops; (5) hot-plates and stoves for lacquering purposes; and (6) goose irons for tailors. The advantages of electricity for use in all these cases are given in detail; the chief points being—cleanliness, fire-risks, efficiency, regulation of temperature, and quantity of work turned out.

For cooking purposes the use of electricity will not cost an excessive amount if current can be purchased at 1*d.* or 1½*d.* per unit, and if some other means is provided for heating the usual large quantity of water required for domestic purposes. Electrical radiators for small rooms and for intermittent heating, even when supplied from central stations, will compare favourably with other forms of heating. With rooms over 5,000 cubic feet in size, and

in rooms where continuous heating is required, electrical heating becomes too expensive. The average power required for heating a room is about 500 watts per 1,000 cubic feet of volume; and during the coldest weather this power will be required for two or three hours to raise the room temperature to about 65° F. The power may afterwards be reduced to about $\frac{1}{3}$ or $\frac{1}{2}$. The best design of radiator is one which has a free draught and circulation of air through it. The first cost of radiators per 100 cubic feet of room volume is given as: 6*s.* for rooms up to 1,000 cubic feet in volume, 4*s.* 6*d.* for rooms up to 2,500 cubic feet in volume, and 3*s.* 6*d.* for rooms up to 5,000 cubic feet in volume.

It may be taken as a general rule that, if the degree of temperature required for an operation exceeds 500° F., there will be difficulty in making electrical heating apparatus durable and satisfactory for general working.

E. D. P.

A 35-ton Electrical Travelling Crane.

(Éclairage Électrique, 1899, pp. 389–391. Génie Civil, xxxv., 1899, p. 408; from the Zeitschrift des Vereines Deutscher Ingenieure.)

A description and drawing of a heavy overhead 3-motor traveller, having a span of 16 metres in a boiler shop. The 15-HP. hoisting series motor raises loads of 20 tons to 35 tons through 1·3 metre per minute, and higher loads at 2·7 metres per minute. The bridge is travelled at 40 metres per minute by a 10-HP. series motor carried at the centre, and the carriage at 15 metres per minute by a 5-HP. motor. An electric brake is automatically applied when the motor is stopped, and removed on starting up. The hook is double; it turns on ball bearings and is carried by three chains.

E. H. C.-H.

Electrical Travelling Cranes.

(Engineering, January 5, 1900, pp. 13–15.)

The most advanced practice in overhead travellers is to use a separate reversing motor for each motion; the Paper describes and illustrates a 50-ton crane so constructed by J. Adamson & Co. of Hyde, Cheshire. The crane has four motors to drive the main barrel, the light barrel, the longitudinal motion, and the transverse motion respectively, with current at 220 volts. The main lifting speed is 4 feet per minute, the lifting barrel being 2 ft. 6 in. diameter, the corresponding motor running at 400 revolutions per minute, and there being three intermediate shafts between the motor and the barrel. The light lift is intended for loads up to 5 tons, the speed of lifting is 15 feet per minute and the speed of the

motor 300 revolutions per minute. The speed is reduced at two steps by a worm gear and a pair of spur-wheels, the worm gear running in an oil bath. Both lifting drums are controlled by electric brakes. The brake wheel is pressed on by shoes applied by springs and released by an electromagnet which is energized when the current is directed to the corresponding motor. Should the current fail from any cause the brake goes on immediately and holds the load; on the other hand, immediately the crane is set to lift or lower, the brake is taken off. Should the load in falling drive the motor too rapidly, the back electromotive force reduces the current and the brake goes on of itself. The longitudinal travel of the crane takes place at a speed of 80 feet per minute, the speed of the motor is 300 revolutions per minute, and the reduction is effected in two stages. The transverse motion is at 40 feet per minute, and the motor runs at 500 revolutions per minute. The power absorbed by the motors when the crane is fully loaded is as follows: Main hoist, 25 B.HP.; auxiliary hoist, 12 B.HP.; traversing, 7 B.HP.; longitudinal travel, 5 B.HP. Curves are given showing the efficiency of the main and auxiliary hoisting gears at various loads. At 30 tons load the efficiency of the main hoisting gear attains its maximum value of 63 per cent.; the efficiency falls to 56 per cent. for the full working load, 50 tons. The maximum efficiency of the auxiliary hoisting gear is 55 per cent., the corresponding load being 3½ tons.

A. S.

Electrically-driven Jacks.

(Electrical Review, March 2, 1900, p. 345.)

In the locomotive works at Nippes, in Germany, each 12-ton jack was manned by five men; to raise a four-axle locomotive required 21 men for the four jacks. The average time for the lifting was 45 minutes and for the lowering about 30 minutes. In consequence of the variations in the time for each lift, depending on the willingness of the workmen, mechanical power for the operation of the jacks was introduced. Rope driving was tried and discarded. Compressed air and electrical power were both available at the works and were both tried. In comparison with the electrical gear the compressed-air gear was complicated, and the cost of the electrical energy consumed was less than the cost of the compressed air used.

The electric motor used is mounted on a small car; the two jacks at one side of the locomotive are connected to the motor by solid spindles sliding in a hollow shaft on the feather and groove principle, a Hooke's joint being introduced to compensate for inequalites of level. The other two jacks are driven by chain gearing. The motor is of 5 H.P., and by means of main and shunt-circuit resistances has a range of speed from 300 to 1,035 revolutions per

minute. Absolute evenness of lift by each jack is ensured in this way, and a considerable saving in time and labour is effected. The time occupied in raising a locomotive is 12 minutes, the lowering taking about the same time. At 110 volts a current of 35 to 38 amperes is required for raising and 20 to 25 amperes for lowering. The labour, including the shifting of the motor, can be supplied by two men.

Taking wages at 5*d.* per hour and electric energy at 2*d.* per kilowatt-hour, the cost for hand manipulation works out at 10*s.* 11*d.*, as compared with 6¾*d.* for electric driving. Interest, depreciation, and maintenance are not taken into account in this comparison. Allowing 1*s.* per hour for this amount, as representing a fair amount for a capital outlay of £600, the saving effected by electrical driving would be almost 10*s.* per lift.

E. D. P.

Transforming-station of the Buffalo General Electric Company.

(American Electrician, February, 1900, pp. 59–67.)

The Niagara Cataract Power and Conduit Company delivers 3,000 HP. three-phase current at 350 volts and ·25 cycles per second to the central station of the Buffalo General Electric Co. This central station delivers four classes of service; namely, constant current for arc lights, 62 cycle alternating current for the incandescent lighting in the scattered districts, 500-volt direct current for motors, and 220-volt three-wire direct current for the local incandescent lighting. The station is unique in that there are no steam or hydraulic prime movers, all mechanical power being obtained from alternating current motors fed from Niagara.

The plant consists of fourteen 150-kilowatt induction motors driving twenty-eight 125-light arc machines; two 425-kilowatt induction motors driving single-phase alternating current generators, giving current at 62 cycles per second; one 425-kilowatt induction motor driving two direct-current generators, each 200 kilowatts, 130 to 190 volts; two 200-kilowatt and two 100-kilowatt rotary converters; two 30-HP. exciter sets; 150 chloride (75 on each side) accumulator cells having a rated capacity of 3,000 amperes for a 1½-hour discharge rate.

The original apparatus for supplying the direct-current load consisted of two 100-kilowatt 125-volt rotary converters, which were run in series with each other on their direct-current ends across the three-wire system. The machine is illustrated, and attention is drawn to the fact that the commutator has practically the same length and diameter as the armature itself, this being due partly to the low voltage and also to the fact that a three-phase rotary converter can be made to deliver considerably more

current without overheating than the same armature and fields would generate if mechanically driven as a dynamo.

A peculiarity of rotary converters for lighting service is the fact that the voltage of the direct current output is always exactly proportional to the alternating voltage on the collecting rings. If the latter varies due to changes of load and drop in the alternating current system, the direct voltage varies with it, thus requiring as perfect regulation (so far as momentary changes of pressure are concerned) in the alternating system as is needed for the direct-current incandescent lighting. On this account, and in spite of the greater cost and lower efficiency of motor generators as compared with equivalent rotaries, the additional transforming apparatus which has been installed is in the form of a motor generator in which the direct current is quite independent of the varying drop in the transmission line and any sudden reactive drops in the transformers when alternating current motors are started. The motor generator has proved so very convenient that the company is about to add a further unit, consisting of two 400-kilowatt dynamos, driven by a 900-kilowatt induction motor.

It may be mentioned that the regulation of the voltage of the rotary converters is partly effected by reactive coils, consisting of series windings on laminated iron cores, the three cores of the three phases forming mutual magnetic returns for each other. These coils introduce self-induction into the alternating current circuits, and such self-induction can be utilised by means of leading or lagging currents, to give a boosting or depressing effect upon the voltage, the leading and lagging currents being introduced by strengthening or weakening the field excitation of the machine. If the *field of the rotary is strong*, leading currents are drawn through the reactive coils and set up therein an inductive counter electromotive force, which on account of its phase relation adds to the original impressed electromotive force. If the *field of the rotary is weak*, lagging currents are drawn through the reactive coils, and the inductive counter electromotive force swings round, so that it now opposes the impressed electromotive force, and so lowers the voltage. The result, so far as practical operation is concerned, is about the same as in the direct-current dynamo, *i.e.*, the field of the rotary is strengthened to increase the voltage and weakened to lower the voltage. By means of these reactive coils a range of pressure of about 12½ volts can be obtained.

The switchboard, which is fully described, is arranged for the rotaries, motor generators, and storage batteries being run in parallel. Detailed particulars are given of special swivel switches for the direct-current side of the rotaries; of a special field switch made in the hatchet form; and of the motor-driven-end-cell-regulating-switches for the chloride accumulators.

The demand for energy throughout the twenty-four hours averages about 2,200 HP. The battery carries the three-wire incandescent load during the evening without any help from the

machines, the motor generator and the rotaries being shut down so as to reduce the load peak. During the day, when the arc and incandescent load is very light, the motor generator is run to carry the 220-volt load and charge the battery. As soon as the battery is charged, the motor generator is shut down, the rotaries being then started up to carry the three-wire load.

E. K. S.

Development of the Niagara Power System.

J. E. WOODBRIDGE.

(American Electrician, January, 1900, pp. 1–20.)

The general design of the recently added alternators (there are now ten generating units each 5,000 HP.) is the same as before, that is, an umbrella type of field rotating about an internal stationary armature. There are, however, some changes in detail with a view to the better dissipation of the heat, for although the machines have the extremely high efficiency of 98 per cent., the 2 per cent. wasted amounts to so much as 100 HP. The spiders holding the two bearings are forced downwards by means of bolts into tapered seats, bored in the interior of the frame. The bearings themselves are also forced to a tight fit in the spiders, and are piped to an oil system, a screw pump lifting the oil to a reservoir placed under the eaves of the power-house, from which it circulates by gravity through the bearings and down again to the pit. An oil recuperating system is provided, consisting of tanks, in which the oil is boiled and then filtered; the boiling is accomplished by means of electrical heaters, its purpose being to drive off any water that may become mixed with the oil.

To keep the bearings cool, holes are cored out which are connected with water-pipes. The frame has vertical ribs in which the armature laminations are dovetailed, and through these ribs run vertical passages which carry water for the purpose of cooling the armature core. Pipes connect the lower ends of these passages, while the upper ends are capped and connected together by means of small square cross passages cored in the casting.

The field cores are made up of bare copper strip wound edgewise, but differing somewhat from usual edgewise coils in that there are four layers. The four layers are separated from each other, and rigidly held in place by means of metal spacing rods covered with mica and shellac insulation. Between these spacing rods there is ample room for the ventilation of each layer, circulation of air being permitted by means of ventilating openings in the casings. The edgewise turns of each layer are insulated from each other by strips of built-up mica and shellac insulation.

The new main turbine wheels are controlled by magnetic clutch governors designed by Coleman Sellers, in which centrifugal

weights operate contacts in an oil bath, and these contacts close the circuits of electromagnetic clutches, one for the opening and the other for the closing motion of the gates. The alternators are shut down by simply opening the field circuit, the same action starting the governor into motion to shut off the water from the main wheels. Circuit-breakers in the field circuits of the machines are wired to an emergency switch, by closing which the fields of all the machines running in parallel with each other may be opened simultaneously in case of emergency, and the gates of the water-wheels of the same units may be at the same instant started towards the closed position.

A long and interesting account is given of the transmission of 15,000 HP. to the works of the Union Carbide Co. Although the distance transmitted is only 11,000 feet, it has been found worth while to step up from 2,200 volts two-phase to 11,000 volts three-phase, the transformers, six in number, being connected on the system introduced by C. F. Scott. The output of each transformer is 2,500 HP.; they are made by the Westinghouse Co. and are oil-insulated and water-cooled. At the works of the Carbide Co. the voltage is reduced in two steps from 11,000 volts down to 110 volts, the first step by means of six units exactly similar to the step-up transformers, and the second step by means of ten 2,000 HP. step-down transformers which have been supplied by the Wagner Co.

A number of interesting details are given of the construction of all the transformers, including those of the air-blast type supplied by the General Electric Co. Efficiency curves are given.

The heavy switching work in the Niagara power-station is done by compressed air, which is obtained from a water-driven Worthington pump. Most of the circuit-breakers are fitted with a time-element device which has for its object to prevent a short-circuit at a point distant from the power-house, opening any but the nearest circuit-breaker to it. Two methods by the Westinghouse Co. (Stillwell) and the General Electric Co. are described, as well as the *reverse current* circuit-breaker mechanism as used on the Niagara-Buffalo transmission line.

Particulars are given of a special Westinghouse 450-kilowatt transformer, giving 37,500 amperes at 12 volts. The transformer has a single secondary turn, and the pressure is regulated from 12 volts to 30 volts by changing the number of turns on the primary side.

On the Niagara-Buffalo transmission line the voltage is 11,000, and the wires are arranged triangularly 3 feet apart and spiralled at intervals. The maximum load at this voltage is about 10,000 HP., so that, in order to allow for the expected increase of load, it is proposed to raise the line pressure to 22,000 volts, besides erecting another pole line to Tonawanda. The guard wires which were intended to serve as lightning arresters have been taken down, as the trouble they caused through falling proved greater than any probable benefits. Lightning arresters are in use at the

transmitting end, and also at the Tonawanda substation and at Buffalo, where the line goes underground.

The article closes with an account of the work of the Cataract Power and Conduit Co., which assumes control over the transmission line where it enters the Buffalo City limits and handles the power from that point to consumers' premises. A number of interesting particulars are given of the various underground cables and of the substations. Amongst customers for power are the Buffalo General Electric Co., 3,000 HP.; the International Traction Co., 5,000 HP.; a large grain elevator, 1,000 HP.; whilst the Union Dry Dock Co. operates its extensive workshops, &c., entirely by means of induction motors, practically every machine, tool, elevator, crane, &c., having its own motor belted to it.

E. K. S.

Ducasse Electric Furnace.

(Ind. Électrochim., November, 1899, pp. 116–117. From the *Ingénieur français* through *Electro-chimie*, 1899, p. 174.)

The furnace is circular in plan with a movable hearth, the whole of which acts as the negative electrode. A tap-hole is provided to run off liquid smelting-products, and in the upper portion of the furnace is a side flue, provided with a sight-hole and cleansing-door; through this flue the heated furnace gases are carried to a chamber in which the furnace-charge is preheated. The furnace is surmounted with a domed cover fitted with an eye-bolt by which it may be raised from its position, and perforated with charging doors, and with four apertures, through each of which passes one of four carbon rods forming the positive electrodes. These electrodes are supported from above in such a way that their position may be regulated automatically or at will. By means of a motor working on a shunt from the main circuit, a rotary current-distributor causes the main current to pass through each of the electrodes in succession 3,000 times a minute, contact with any one carbon not being broken until that with the next has been made, so that sparking is avoided. There is in this way produced in the hearth of the furnace an arc which practically rotates at 3,000 revolutions a minute.

W. G. M.

Cable-Core Design. F. Breisig.

(Elektrotechn. Ztschr., November 30, 1899, pp 842–845. Communication from the Kaiserl. Telegraphen-Versuchsamt.)

Various types of core are compared with regard to the "speed" at which legible signals can be transmitted through them. It is assumed that resistance and capacity cannot be reduced without

increase of cost, and that a possible way to improve transmission is to introduce self-induction into the core, either by one of the various devices suggested by S. P. Thompson, or by combining iron wires or iron tape with the copper conductor. The lengths experimented upon were comparatively short — not exceeding 500 metres. The conductors in each case were insulated with three coats of gutta-percha, sometimes sheathed with steel wires. Alternating currents of known periodicity and of simple sine form were used to represent the working conditions of telegraphy; it is, however, pointed out that the sine form does not accurately correspond to the impulses transmitted through cables. Calculations of the self-induction are based upon the measurement of the alternating volts between the ends of the core and the corresponding alternating current in the conductor. Volts are measured by a compensation method (*Ibid.* p. 448, 1891); current is measured similarly, using either a telephone or an electrodynamometer. The telephone is for this purpose extremely sensitive for 230 ~ and upwards. For lower frequencies the electrodynamometer gives the best results; it is of service even down to 50 ~. But since the zero-reading of the electrodynamometer does not, under the circumstances of a "compensation" method, correspond to a unique relationship between the currents in its respective coils, its indications must be interpreted with caution. Zero may either mean no current or 90° phase difference. As a criterion, a self-induction bobbin connected in series with the fixed coil and provided with a short-circuiting key is employed. The first results relate to the measurement of the capacities of the cables at different frequencies. As the frequency increases from about 270 ~ to about 530 ~, the capacity appears to vary something like 2·5 per cent., sometimes an increase and sometimes a decrease, according to the type of conductor. Similar results are obtained for the impedances and the apparent resistances of the cores at different frequencies; at frequencies from 234 ~ to 427 ~ the apparent resistances are approximately three times the ohmic resistances. The measurements relate (1) to a core whose conductor consists of a round copper wire 2·8 millimetres diameter, covered spirally with four iron strips in one layer to 4·46 millimetres diameter, insulated to 11·59 millimetres, the whole being sheathed with steel wires, the self-induction, as measured, = 0·00370 per kilometre; and (2) to a core whose conductor consists of a central round copper wire 3·10 millimetres diameter, stranded with nine copper wires and three iron wires, each 0·8 millimetre diameter, insulated to 11·76 millimetres, and sheathed with steel wires, the self-induction, as measured, = 0·00262 per kilometre. In another case (3) a central copper wire 2·8 millimetres diameter is stranded with ten copper wires each 1·0 millimetre diameter, insulated to 11·66 millimetres and sheathed with steel wires, the self-induction, as measured, = 0·0235 per kilometre. The self-induction of (1) is thus 1·57 times that of (3). The capacities of (1), (2), and (3) are respectively 0·221, 0·236,

and 0·212 mfd. per kilometre. The resistances are respectively 1·124, 1·112, and 1·125 ohm. These figures show that, in order to keep the resistance approximately the same, the diameter of the conductor has been increased in the case of the strands containing iron, with consequent increase of capacity. Taking these factors into consideration, the maximum increase of "speed" due to the iron in the strand, assuming a true sine-form current, is estimated at 8 per cent. The Author therefore concludes that it is impracticable by any self-inductive device effectively to improve the speed of signalling.

R. A.

Electrical Drawbridge. W. S. Key.

(Elect. World and Engineer, December 23, 1899, pp. 969–970.)

The bridge and approaches over the Charles River, Boston, are 1,920 feet long, of which 1,090 feet is over water. The width of the bridge is 100 feet, and consists of two roadways, one above the other, allowing four car-tracks in pairs. The draw span is 260 feet, and rests on a central pier, giving free passage for vessels 50 feet wide. The air and hydraulic pumps are worked electrically. The draw is opened by two 28-HP. motors, and is operated about twelve times every 24 hours.

M. O'G.

Electrical Operation of Watertight Bulkhead Doors.

R. M. Watt.

(Elect. World and Engineer, December 9, 1899, pp. 895–896. Paper read before the Society of Naval Architects and Marine Engineers.)

The system devised by F. T. Bowles is described. Each door is provided with a separate motor and power circuit, and can be independently operated by hand. The door is of steel plate riveted to a frame which slides in guides; the surfaces nearest the bulkhead are scraped to fit, and are forced together by wedges in the last ½-inch travel. A bronze rack is bolted to the door, gearing through a pinion with another pinion keyed to the shaft of two worm wheels; a worm driven by a motor on the other side of the bulkhead gears with one of the wheels. The motor is of 1 HP., compound wound. A switch fixed by the door is so arranged that the door may be opened or closed from either side of the bulkhead, or closed from a distant station; a limit switch cuts off the current when the door reaches either of its extreme positions. Sprague solenoid gravity controllers are also provided to throw in either the series or the series shunt windings of the motor. To

open or close the door by hand through 6 inches or 12 inches of coal requires from 75 seconds to 85 seconds; these operations are done electrically in 8 seconds to 9 seconds, and require from 3 amperes to 24½ amperes at 115 volts. Signal lamps are used to indicate at the distant station when the door is completely closed or opened.

A. H. A.

Working Expenses of Horse and Electrical Delivery Vans. G. F. SEVER and R. A. FLIESS.

(American Institute of Electrical Engineers, Trans. 1899, pp. 509–531.)

This Paper sets forth the results of an investigation on horse and electric vans belonging to large stores in New York. Their average load throughout the day is 500 lbs., and the average "draw-bar pull" at 7 miles per hour is 60 lbs. per ton on cobble-stones; on asphalt, 40 lbs. The van tested weighed 1,300 lbs. and its horse 1,100 lbs. A day's "log" of a van is given, from which it appears that the average daily work of a horse in such service is 16·5 miles at 50 lbs. per ton at 7 miles per hour, while the cost of horse, van, and attendance is 364 cents per day, or 17·4 cents per ton-mile. If a second horse is kept, these figures respectively become 428 cents per day and 10·2 cents per ton-mile.

A similar "log" for an electric delivery van is given, and shows an average consumption of 92 watt-hours per ton-mile. The Authors are of opinion that 120 watt-hours per ton-mile is a conservative estimate for a well-designed delivery van under service conditions. At 5 cents per kilowatt-hour, the cost per lb. (of parcels only) is 0·019 cent, as against 0·020 cent for horse service, making all assumptions in favour of the horse. Depreciation is not taken into account in any of the figures.

E. H. C.-H.

Cost of Calcium Carbide. H. ALLEN.

(Elect. Rev., January 5, 1900, pp. 7–8.)

The Author bases the estimates given in these notes upon theoretical data, and upon the lowest realised cost for electrical energy when derived from water-power, namely, 0·131*d.* per B.T.U. Using these figures, he estimates that one ton of carbide should cost £9 5*s.* 5*d.* The details of his estimate are as follows:—

	£	*s.*	*d.*
2·143 tons limestone at 10*s.* (crushed)	1	1	5
0·80 ton coke at 20*s.* (crushed)	0	16	0
4374 B.T.U. at 0·131*d.*	2	11	8
Electrode carbons	1	0	0
Labour, oil, waste, interest and maintenance charges	3	16	4
	£9	5	5

The Author states that this result can be improved upon by use of blast-furnace gases for power generation by the Thwaite-Gardner or other system, and reference is made to the installation of the former for carbide production at an ironworks in Westphalia.

J. B. C. K.

Colour Sensations in Terms of Luminosity.

W. DE W. ABNEY.

(Roy. Soc., Proc. 1899, pp. 282–283; and Phil. Trans., 1899, pp. 259–287.)

This Paper deals with a determination of the colour sensations based on the Young theory by means of measures of the luminosity of the three different colour components in a mixed light which matches white. At the red end of the spectrum there is only one colour extending to near C, and there is no mixture of other colours which will match it, however selected. At the violet end of the spectrum, from the extreme violet to near G, the same homogeneity of light exists, but it is apparently due to the stimulation of the two sensations, a red and a blue sensation, the latter never being felt unmixed with any other. By trial it was found that close to the blue lithium line the blue sensation was to be found unmixed with any other sensation except white. The complementary colour to the red in the spectrum gave a position in which the green and blue sensations were present in the right proportions to make white, and a point nearer the red gave a point in which the red and blue sensations were present in such proportions as found in white, but there was an excess of green sensation. The red, blue, and green sensations were thus located. The position in the spectrum of the yellow colour complementary to the violet was also found. The colour of bichromate of potash was matched by using a pure red and the last-named green. To make the match, white had to be added to bichromate colour. A certain small percentage of white was found to exist in the light transmitted through a bichromate solution with which the match was made, and this percentage and the added white being deducted from the green used gave the luminosity of the pure green sensation existing in the spectrum colour which matched the bichromate. Knowing the percentage composition in luminosity of the two sensations at this point, the luminosity of the three sensations in white was determined by matching the bichromate colour with the yellow (complementary to the violet) and the pure red colour sensation. From this equation and from the sensation equation of the bichromate colour already found, the composition of the yellow was determined. By matching white with a mixture of the yellow and the violet, the sensation equation to white was determined. The other colours of the spectrum were then used in forming white, and from their luminosity equations their percentage compositions in sensations were calculated.

The results found from the percentage curves were applied to various spectrum luminosity curves and the sensation curves obtained. Attention is called to the results deduced from these curves and from other curves obtained from them, and the difference between Koenig's determination and that of the Author is pointed out.

J. J. S.

Magneto-Optic Rotation. J. Larmor.

(Cambridge Phil. Soc., Proc. 1899, pp. 181–182.)

When in a material molecule there exists an independently vibrating group of ions or electrons, for all of which the ratio $\frac{e}{m}$ of electric charge to inertia is the same, then the influence of a magnetic field H on the motions of this group is precisely the same as that of a rotation with angular velocity ω, equal to $\frac{\frac{1}{2}eH}{mC^2}$, imposed on the group around the axis of the field, on the hypothesis that the extraneous forces acting on the ions are symmetrical with respect to this axis.[1] This result involves the main features of the Zeeman effect; it requires that the separations of the doublets representing the spectral lines arising from such a group must all be equal when measured in difference of frequency, or be inversely as the square of the wave-length in vacuum when measured in difference of wave-length, a relation which Preston has recently found to obtain for the natural series of lines in ordinary spectra.

The Author here points out that it is possible to deduce the Faraday effect from the Zeeman effect by general reasoning as regards any medium in which the optical dispersion is mainly controlled by a series of absorption bands for which the Zeeman effect obeys the above law, without its being necessary to introduce any special dynamical hypothesis. For this law ensures that the effect of the magnetic field on the periods of the corresponding free vibrations of the molecules is the same as that of a bodily rotation, say with angular velocity ω, round its axis; while the complete circular polarizations of the Zeeman doublets, viewed in the direction of the axis, show that their states of vibration are symmetrical with respect to that axis. Thus Ω being the angular velocity of the displacement vector in a train of circularly polarised waves traversing the medium along its axis, the state of synchronous vibration which it excites in the molecules will have exactly the same formal relation to this train when the magnetic field is off as it would have to a train with the very slightly different angular velocity $\Omega \pm \omega$ when the magnetic field is on, the sign being different according as the train is right-handed or left-handed. Now change

[1] Phil. Mag., Dec. 1897.

of this angular velocity Ω means change of period of the light; thus the propagation of a circularly polarised wave-train, when the field is on, is identical with that of the same wave-train when the period is altered by its being carried round with angular velocity $\pm \omega$, and there is no influencing magnetic field. This last result has been employed by Becquerel as a single hypothesis from which to deduce quantitatively both the Zeeman effect and the Faraday effect, and thus correlate them.[1]

The preceding argument forms a general dynamical justification of this hypothesis for the case of all media in which the ordinary gradient of dispersion is mainly controlled by one or more powerful absorption bands beyond the visible spectra, for which the Zeeman constants are the same; it also shows that Becquerel's hypothesis has an approximate validity when these constants are nearly the same for all the effective bands. In the immediate neighbourhood of any single band the dispersion is anomalous, and is controlled practically by that band alone: the application will then be exact, and in Becquerel's hands it has given a complete account of the excessive and anomalous Faraday rotation first observed by Macaluso and Corbino in sodium vapour for light adjacent to the D lines. These simple general conclusions are consistent with the results of the more special dynamical investigations by Fitzgerald and Voigt.[2]

J. J. S.

Thermal Conductivity of Heat Insulators.

C. G. Lamb and W. G. Wilson.

(Roy. Soc., Proc. 1899, pp. 283–288.)

A method of testing the comparative efficiency of materials used as insulators is described. The method was devised with the object of using lower temperatures and smaller ranges than had been used in previous experiments, to attain a perfectly steady state of heat transference, and allow of greater accuracy and simplicity in the measurements. The substances used were tested in the dry state, and include air, sawdust, charcoal, hair felt, &c. The method used consisted in placing the material under test in the space between two cylindrical copper pots, kept at a definite distance apart by pieces of vulcanised fibre; the inner pot contained a small motor with a fan attached to its axis; a tin-plate cylinder, open at the top and with holes at the bottom, was put inside to direct the currents of air over the inner surface of the inside pot. Energy was supplied electrically to a heating coil within, as well as to the motor: this constituted an internal supply of heat, which maintained the temperature within the pot at any decided upper limit. The

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[1] Science Abstracts, 1898, No. 115.

[2] *Ibid*, 1898, Nos. 115–120, and 755–759; 1899, Nos. 246, and 422–427.

motor and coil were connected in series, and leads were carried through a small hole in the lid of the pots to measure the current and potential difference, and thus the power expended on internal heating was measured. The outer pot's surface was kept at a uniform and constant temperature by being immersed in a tank through which water flowed from the mains. The resulting temperature differences were measured by means of thermo-electric junctions of copper and iron. The current was passed steadily into the inner pot, driving the motor and fan, until the inner thermo-electric junction arrived at a steady value; this usually occurred in about three hours; when this was the case the supply of energy by the current was just equal to the heat conducted through the insulator and carried off by the water. Knowing the temperature gradient and the number of watts supplied and the dimensions of the system, the specific conductivity of the material can be deduced.

The following results were obtained:—

Material.	Conductivity.
Air (no baffles)	0·000200
Pine sawdust	0·000242
Pine shavings	0·000162
Brown paper (crumpled up)	0·000167
Hair felt (broken up)	0·000145
Hair felt in two sheets ½ inch thick each	0·000106
Dry asbestos	0·000297
Charcoal	0·000150
Sand	0·000740
Rice husks	0·000150
Kapok (a heat insulator)	0·000144
Kapok (loose)	0·000122
Silicate cotton	0·000151

In these experiments the temperature differences varied from about 8° to 28°. Hair felt was the best insulator tested. The insulation in the case of brown paper was practically that of air with subdivided spaces; the improvement thus produced in comparison with air only is noticeable.

J. J. S.

Hysteresis of Resistance. H. Chevallier.

(Comptes Rendus, January 15, 1900, pp. 120–122.)

When a wire is subjected to periodic variations of temperature its electric resistance varies in a very irregular manner. If R is its resistance at a temperature T_0, and it is heated to a temperature T_1, and subsequently cooled down to T_0, its resistance will finally be different from R. The difference is due to some allotropic transformation undergone by the metal, which is subject to hysteresis. There is not only a change of temperature, but also a complication introduced by the alternate annealing and tempering of the wire. The Author's experiments dealt with a silver platinum alloy which

resists oxidation. He made the temperature oscillate a large number of times between T_0 and T_1, and found that the resistance at T_0 acquired values differing from each other by a less and less amount as the alternations proceeded, without the difference, however, disappearing entirely. Several series of 70 oscillations each between 150° and 15° gave final values for 15° amounting to 1·01509, 1·01500, 1·01493, 1·01490, 1·01488, and 1·01487 respectively. The last limiting value is practically final for 15°, but it is disturbed by heating the wire to a temperature above 150°. By repeating the oscillations and introducing the disturbance systematically the Author obtains a limit of the limits which completely fixes the final temperature for the range and disturbance specified.

E. E. F.

Magnetization of Brickwork by Lightning. P. Gamba.

(Accad. Lincei Atti, 1899, pp. 316–320.)

The Author describes several well-marked instances of the magnetization of masonry struck by lightning. In a house near Viterbo several magnetised portions of a wall were discovered, one of which marked a point passed through by the discharge. The Author believes the magnetization to be quite independent of terrestrial magnetism, and solely due to the direction of the discharge. He believes with Folgheraiter that most of the fragmentary rocks of the Roman Campagna which exhibit magnetic polarity acquired it through lightning discharges.

E. E. F.

Application of the Phase Law to Alloys and Rocks. H. le Chatelier.

(Comptes Rendus, January 8, 1900, pp. 85–87.)

The Author first enunciates the phase law in the form $v = n + p - r$, where v = number of degrees of freedom of system, n = number of independent components, p = number of variable physical parameters, and r = number of phases. If temperature be the only physical parameter which is variable, then $v = n + 1 - r$. If we now consider a mixture of solid bodies at ordinary temperatures, obtained by a series of reversible transformations (such as solidification by cooling, crystallization from a solution, &c.), the result will be a stable solid mixture whose temperature may be varied within finite limits without any one of the phases necessarily disappearing. Hence $v = 1$ and therefore $n = r$. We thus arrive at the proposition: "The stable state of a solid mixture obtained in this way is such that the number of phases present is equal to the number of independent constituents."

F. G. D.

Electrochemical Equivalents of Copper and Silver.

T. W. RICHARDS, E. COLLINS, and G. W. HEIMROD.

(Proceedings of the American Academy, 1899, pp. 123–150.)

Metallic copper dissolves in an acid solution of copper sulphate, even when free from air and protected by an atmosphere of hydrogen, giving rise to cuprous sulphate; a deficiency is thus caused in the deposit of metal which is proportional to the area of the plate, and can be corrected for by extrapolating to a plate of zero area. In a neutral solution, on the other hand, the values are too high, owing to the deposition of cuprous oxide on the kathode; the solution employed must therefore be acid. By reducing the area of the kathode the error due to dissolution of the copper can be materially reduced, but if the current density becomes at all high, the weight of metal is reduced owing to the deposition of hydrogen in place of copper; this effect is most pronounced in dilute solutions, which might otherwise be employed with advantage to reduce the error due to dissolution of copper.

The best values for the electrochemical equivalent of copper are obtained only when the following precautions are used: (1) The solution must be cooled with a freezing mixture; (2) it must be acidified to prevent hydrolysis of the cuprous sulphate and precipitation of cuprous oxide on the kathode; (3) it must be as dilute as is consistent with preventing the liberation of hydrogen; (4) air must be excluded. By adopting these precautions and extrapolating to a plate of zero area the maximum atomic weight of copper has been found to be 63·563, taking that of silver as 107·93 and using the ordinary form of silver voltameter. Using a cupric solution already saturated with cuprous sulphate, higher values were obtained, viz., 63·573 at 0° and 63·615 at 60°.

The ordinary form of silver voltameter has been shown by a number of observers to give variable results owing to secondary actions, accompanied by the liberation of acid, at the anode. These sources of error are very largely eliminated by enclosing the anode in a porous pot instead of a filter paper, and keeping the level of the liquid lower inside than outside the pot. Under these conditions the electrochemical equivalent of silver was found to be 0·0011173 gramme per ampere-second, and that of copper becomes 0·0003292 gramme per ampere-second when the corrected value for silver is used; hence also 96,610 coulombs correspond to one gramme-equivalent of an electrolyte. The atomic weight of copper, determined from the corrected electrochemical equivalent is shown to lie between 63·598 and 63·615, and agrees closely with the value 63·604 obtained by chemical methods.

The Paper contains full references to the work of Foerster and Siedel, Kahle, Patterson, and Guthe, and other workers on the subject.

T. M. L.

Villon Process for Manufacturing Alcohol.

(Electrical Review, New York, 1899, p. 375.)

The Villon process for the manufacture of ethyl-alcohol is now in operation in Russia, and the product is being used as a fuel in motor vehicles. The raw materials of the process are limestone and coke. These are ground, and heated together in an electric furnace in order to produce calcium carbide. The carbide is then decomposed with water in the usual manner, and the resulting acetylene gas is converted into ethylene gas by allowing it to pass through a solution of chromium and ammonium sulphates, maintained at a temperature of 40° C. The ethylene gas is then absorbed in sulphuric acid, and the hydrogen-ethyl-sulphate obtained in this way is distilled after the addition of water. The distillate is condensed and is ethyl-alcohol of a very pure character. It is stated that with carbide at $20 per ton, the cost of the alcohol is 8 cents per gallon. Figures showing the apparatus used in this method of manufacture are given.

J. B. C. K.

Cure of Electrolysis by Independent Earth Returns.

C. A. Newbaker.

(American Electrician, February, 1900, pp. 72–74.)

The streets of large cities are particularly favourable to electrolytic action on lines of metal laid under them, because the ground contains a large accumulation of impurities which form acids and alkalies for electrolytes. Lead has a high electrochemical equivalent; that is, a large amount of it is dissolved per ampere-hour of current flowing from it, and therefore unfavourable earth conditions cause its rapid decomposition.

A peculiarity of electrolytic action is that no metal is dissolved where the current flows into a pipe, but all metals are liable to be attacked by current leaving the pipe and flowing into the material surrounding it. On account of this and the fact that the positive pole of the dynamos is to line, the tendency is to localise all the trouble in the district near the power-house.

The independent return method of curing electrolysis consists in running metallic connections from all underground piping, cable sheathing, etc., to the return circuit of the traction system at all points where the current tends to leave the piping and return to the traction circuit. Current leaving the pipes *viâ* a metal path does no harm, and as the current entering the pipes is also harmless, this method, where thoroughly carried out, is a very satisfactory one. The return should be of stranded copper (tinned) connected to lead cable sheath by means of a looped joint and to

the tram rails either by a soldered joint to a cross bond or by a separate bond to the track itself.

Thorough tests should be made for electrolysis at intervals of 6 months or oftener if changes in the conditions of distributing power are known to have occurred. A telephone company, for example, may at one time make tests and find that its system is, on the whole, safe, and a little later find that a highly dangerous condition exists. This sudden change may be due to a lowering of the potential of the ground below that of the track by auxiliary returns run by some other corporation operating over the same territory, such as a water or a gas company. This is a condition to be watched for at all times, as the protection of one set of pipes is likely to cause danger to another.

The Author describes a method of making systematic tests and how to plot curves showing the distribution of potential over a piping system and adjacent ground before and after using an independent return, etc. The edges of the hole burned into the cable sheath by a heavy current are square as though the hole were punched out, whereas the edges of a hole made by electrolysis are thin like those of a dull knife-blade. Electrolysis always causes grainy, rough surfaces, and its apparently freakish tendency to attack in spots and form ridges is probably due to a lack of homogeneity in the metal.

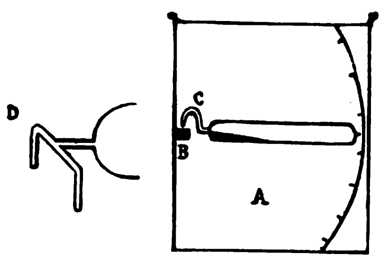
The current in a return may be read by a milli-voltmeter giving the voltage between two points a few feet apart, the current being calculated on the basis of 10 ohms per foot per circular millimetre. This obviates the necessity of cutting the return to insert an ammeter.

E. K. S.

Hydrometers of Total Immersion. G. Guglielmo.

(Accad. Lincei Atti, 1900, pp. 33 *et seq.*)

The hydrometers described are totally immersed, thus avoiding any disturbance due to surface tension. One, shown in the figure,



is of constant weight but variable inclination, the reading of the density depending on the angle of inclination, whilst the other is

of constant inclination but of variable weight, the reading of the density depending on the weight added. In the figure A is the vessel, B is the support of the hydrometer, C and D indicate the way in which the instrument is supported.

A. G.

Paris Exhibition Telescope. J. N. Lockyer.

(Nature, 1899, pp. 178–181.)

Several articles have been written on this instrument, giving isolated details; the present one is more complete. It is hoped that the magnifying power employed under good observing conditions will show the moon's surface as if it were only 67 kilometres distant, so that any feature more than 1 metre square may be detected. The focal length is 100 metres (328 feet) or about 4½ times that of the Yerkes telescope. The glass mirror, 2 metres diameter, was cast at the Jeumont glass works under the direction of Despret, and has a thickness of 30 centimetres, weight 3,600 kilograms. The advantage of reflecting the light from a celestial object from the mirror of a siderostat driven by clockwork into the fixed telescope is manifest in an instrument of this size, as a dome 340 feet in diameter would have been necessary, the mechanical difficulties in constructing and moving which would have been enormous. Besides this, the use of the siderostat ensures greater stability, and saves the observing astronomer much unnecessary fatigue and loss of time in that he has never to change his position of observation.

The pedestal for the siderostat is 8 metres high and 8 metres long, resting by six screws on a stone slab 1·70 metre high. The north part of the pedestal supports the polar axis with driving and position circles, and also the sliding pivot for the declination circle. The mirror and cell together weigh 6,700 kilograms. The cell of mirror is lined with felt and the weight of the mirror is distributed by a carefully adjusted system of levers and counterpoises, and in addition, at the base, the whole framework rests in a basin of mercury, the quantity of which is adjusted so as to float about nine-tenths of the whole movable weight. The total weight of the siderostat is 45,000 kilograms.

The telescope proper is provided with two object glasses, one for visual work, the second for photography. Each is 1·25 metre in aperture. The glass for these was made by Mantois, and the final optical grinding and finishing is by Gautier. The flint lens weighs 360 kilograms, the crown 220 kilograms. The telescope tube is of sheet steel, 2 millimetres thick, 1·50 metre in diameter, and weighs 21,000 kilograms. It is supported horizontally on eight cast-iron brackets resting on stone pillars. Both objectives are mounted on the same carriage, by which either can at once be

placed in line with the tube. The eyepiece tube is double, the interior part being rotated by clockwork, so that the movement of the stars is neutralized. Illustrations are given showing the various parts to scale.

C. P. B.

Electrical Discharge in Large Quantity. J. Trowbridge.

(Electrical Review, New York, January 3, 1900, p. 5.)

This short note accompanies two photographs of electric discharges of very large quantities. One hundred and fifty plate-glass condensers, 18 inches by 20 inches by $\frac{1}{8}$ inch thick are arranged in multiple and charged to 20,000 volts by means of 10,000 Planté cells. One photograph represents the deflagration of 6 inches of No. 30 iron wire and the other the deflagration of a similar piece of wire arranged as a shunt to a spark-gap. A spark occurs at the spark-gap simultaneously with the deflagration of the wire.

The Author therefore concludes that a spark might occur inside a metallic cage when large quantities are in question. A cage would not, therefore, in all cases completely protect a powder magazine against lightning.

J. B. H.

Application of Braun Tube to Study of Hysteresis. K. Ångström.

(Electrical Review, New York, January 10, 1900, p. 38; Physical Review, February, 1900, pp. 74–82.
Paper read before the Kongl. Vetenskaps Akademie.)

Four coils, spaced 90° apart, are connected in series and are arranged with their axes in a plane close to the diaphragm of a Braun tube. One pair of coils, whose axes are along a vertical diameter of the tube, contains no iron cores, so that their deflecting effect on the kathode rays is proportional to the current, and hence to the magnetic force. The horizontal pair of coils, on the other hand, contains samples of the material to be tested. The deflecting effect of this second pair of coils is proportional to the magnetization of their cores. If the two sets of coils are connected to a source of alternating electromotive force, a fluorescent hysteresis loop appears on the screen of the Braun tube. Specimens of loops obtained in this manner are given. The following modification is suggested by the Author for comparing different samples. Each of the two horizontal coils contains a different sample (instead of identical ones as in obtaining the ordinary hysteresis loops), and

the vertical coils are entirely removed. If the two samples are of precisely the same magnetic quality, a simple rectilinear vibration will result; but the slightest difference between them will be exhibited by a characteristic curve.

A. H.

Electrical Tramways and Magnetical Observatories.

V. BEZOLD.

(Elektrotechnische Zeitschrift, February 22, 1900, pp. 161 *et seq.*)

Upon the basis of the researches of Eschenagen and Edler, at Potsdam and Spandau, the Author pleads for the protection of magnetic observatories from disturbance due to earth returns of electric railways. He shows that terrestrial magnetism was the parent and precursor of electric telegraphy and of the whole of electro-technology, that it involves enormous commercial interests, and that it is in imminent danger of being made a science impossible to prosecute. For the purposes of modern navigation it is essential that magnetic charts should be republished every 5 years, and the revision cannot be successfully carried out without fixed points analogous to the fundamental points of a trigonometrical survey. In countries where, as in the United States, the boundaries of territories and states are fixed by the compass, endless legal difficulties are occasioned by slight errors in the magnetic variation. Earth returns have already ruined the work of the Washington, Toronto, Vienna, Nice, Copenhagen, and Batavia observatories, and others are threatened. It is practically impossible to secure sites away from possible disturbances, unless magneticians of high standing are to share the fate of lighthouse-keepers. Metallic returns appear to be the only efficient safeguard.

E. E. F.

Electrolytic Treatment of Urethral Stricture. R. NEWMAN.

(Archives d'Él. Médicale, March, 1900, pp. 116 *et seq.* Translated from the Journal of Electrotherapeut, New York, March, 1899.)

The Author has successfully employed electrolysis in more than one thousand such cases during the course of 30 years. This treatment has proved successful beyond doubt. Many practitioners, not understanding the method, avoid it, because our medical colleges give little or no instruction in electro-therapeutics. The pathology of stricture is entered into, and it is pointed out that progressive dilatation is an ideal treatment in cases of slight pathological alterations in the mucous membrane; but it is not competent to deal with submucous infiltrations and fibrous forma-

tions more or less profoundly situated. It is then explained that in the eletrolytic method, as in the case of the decomposition of any compound body by electricity, acids and oxygen form at the positive pole producing coagulation, thereby acting as an acid, and leaving a hard elastic cicatrix. At the negative pole there appear hydrogen and bases of salts; albumen is coagulated and absorption produced. This pole acts rather as a caustic alkali. It does not cause much pain during the application, and after the use of a very strong current a cicatrix remains which is soft and non-retractable. The very different results that follow electrolysis depend on the intensity of the current and the duration of the application. For surgical purposes the rule is as follows:—Weak currents produce absorption, strong currents produce cauterization and destruction of tissue. Therefore it follows that in the treatment of stricture weak currents ought to be employed—5 milliamperes or less—using the negative pole. What we aim at is chemical and galvanic absorption. The séances are short (5 minutes to 20 minutes) and repeated at a week's interval. If it is asked, what absorbs? and what is absorbed? the answer is that the galvanic current by the decomposition it brings about absorbs by degrees pathological formations which are encroaching on the calibre of the urethra. Several types of electrodes are employed, the most useful being one with a slight curve and an olive-shaped metallic tip. All the rest of the electrode is of course insulated. The region affected must in the first instance be thoroughly explored. The position of the patient is not a matter of much consequence, and anæsthetization is not necessary, as there is no pain.

W. S. H.

Argon and its Combinations. BERTHELOT.

(Annalen der Physik und Chemie, January, 1900, pp. 66–89.)

From 690 cc. of crude argon, after freeing from nitrogen by sparking with oxygen over potash, or with glycolic ether (one of the best absorbents of nitrogen), there resulted 455 cc. of the pure gas. From 5 cc. to 10 cc. was confined over mercury in a tube enveloped in a large platinum or aluminium spiral. An inverted syphon filled with 10 per cent. sulphuric acid had its inner closed end pushed up into the gas tube. The spiral and syphon being made the two poles of an induction coil, the current traversed the two thicknesses of glass and the annular space of gas, avoiding strong sparks as in an ozoniser. About 0·1 cc. or 0·2 cc. of the liquids under trial was introduced, the very slight solubility of the gas being neglected. The results varied with tension, temperature, and other circumstances. Ethene, glycolic ether, aldehyde, acetone, and compounds of the fatty series generally, while suffering some decomposition, showed no absorption of

argon, and no luminosity in 20–24 hours. With the benzene group combination occurred easily, with a varying green luminosity showing the lines of A, Hg, C, and H, and an absorption from 1 per cent. (aniline) to 8 per cent. or more (benzene). Ring compounds of the C_4 and C_5 groups gave intermediate results. Further experiments were made with benzene in regard to its polymerisation and the formation of *phenylmercurargon*, also with carbon disulphide: 34 of the latter fix 2 of argon, forming a yellowish amorphous solid, from which heat regenerates a small quantity of argon. From the liberation of argon from some minerals the Author argues the existence of *argonides* of the metals.

S. R.

Corrosive and Incrusto-Corrosive Waters in Steam Generators.

H. DE LA COUX.

(L'Éclairage Électrique, January 20, 1900, pp. 98-99, from Génie Civil, December 23 and 30, 1899, and January 6, 1900, vol. xxxvi., pp. 117 *et seq.*)

Three articles in which the corrosive effects of various substances contained in solution in water are examined, and methods of counteracting them are indicated. Some remedies proposed as preventives of the formation of incrustations have also an anti-corrosive action in the case of waters depositing incrustations which by decomposition become corrosive agents. The Author denominates these "incrusto-corrosive" waters. There are also cases in which the remedies proposed against incrustation themselves promote corrosion in boilers using water which deposits innocuous incrustations.

1. Amongst corrosive agents the following are dealt with: HCl and chlorides of magnesium, ammonium, calcium, and sodium; sulphuric acid and sulphates of aluminium and copper; with some general remarks about nitrates, sulphides, sulphuric acid, and H_2S.

2. As remedies against corrosion, notice is taken of the following: Zinc, lime, calcic carbonate, soda, potash, alkaline carbonates, baric hydrate, and carbonate.

The Author made special experiments with other substances, such as salts of lead, alkaline phosphates, silicates, and borates to ascertain the range of their action in boilers.

3. The substances proposed as preventers of incrustation are many, some of them being found amongst those named as anti-corrosive agents—these being thus able to perform double functions. The great matter is to select the reagent best suited to the kind of water used. Magnesia, however, should not be thus employed, because of its forming corrosive compounds with carbonate, sulphate, and chloride of calcium.

4. The Author concludes that the remedies selected should act

equally as regards corrosion and incrustation, not suppressing one action at the cost of favouring the other. For instance, with lime purification can be attained only by an increase of the mass of incrustation; whilst by using magnesia an increase of corrosion may be produced and even a transformation from incrusting to corroding power.

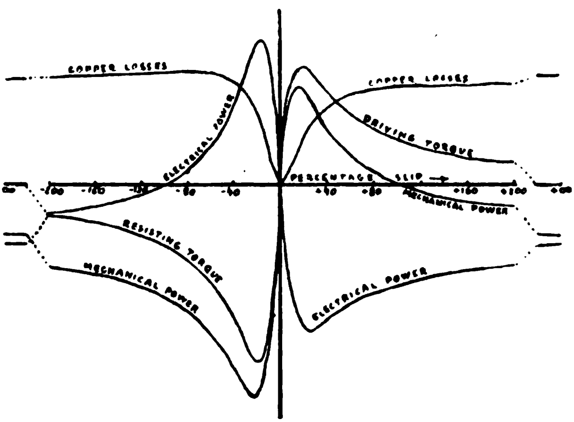
Alkaline carbonates and oxide of barium act perfectly as correctives of incrusto-corrosive waters, because they operate efficiently against both tendencies in the water.

F. J. R.

Theory of Induction Motors. J. HEUBACH.

(Elektrotechn. Ztschr., Jan. 25; Feb. 1, 1900, pp. 73 *et seq.*)

In a former communication[1] the Author considered the application of the Heyland diagram to the study of induction motors under normal conditions of working. In the present Paper, the results then arrived at are extended to include slips ranging from $-\infty$ to $+\infty$. As the Author points out, it may happen that under ordinary conditions of working a motor is made to run with



a negative slip, or with one exceeding 100 per cent. Such cases may arise in the working of cranes which have accidentally been overloaded, or in the case of tramcars running down an incline. Making use of the Heyland diagram, and then plotting the results in rectangular co-ordinates, the Author arrives at the set of curves given above, which show how the various quantities involved vary as the slip changes from $-\infty$ to $+\infty$. The second part of

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[1] Science Abstracts 1899, No. 1976.

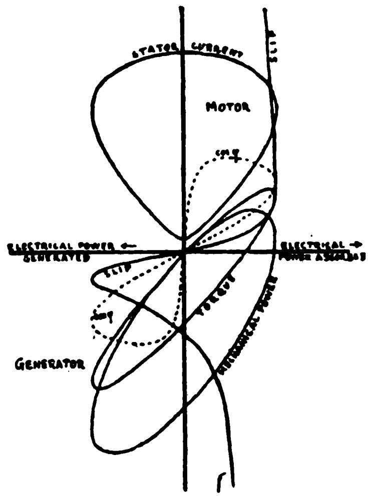
the Paper deals with single-phase motors, the single-phase motor being supposed to be replaced by an equivalent pair of polyphase motors. Curves similar to the above are given for the single-phase motor. In the concluding portion of the Paper, the Author explains how the Heyland diagram must be modified so as to include the hysteresis and eddy-current losses.

A. H.

Theory of Induction Motors. HEYLAND.

(Elektrotechn. Ztschr., Feb. 15, 1900; p. 146.)

Referring to Heubach's article on this subject,[1] the Writer points out that the results obtained by him may be graphically exhibited in a much more striking form by plotting the various quantities



involved, not as functions of the slip,[2] but as functions of the electrical power supplied to, or developed by, the motor. The diagram here reproduced shows the elegant construction which is then arrived at.

A. H.

Lippincott Planimeter. A. G. GREENHILL.

(Engineer, December 22, 1899, pp. 614–615.)

This instrument is a modification of the Hine-Robertson planimeter; the two arms are jointed as in the Amsler planimeter, but whereas in the Amsler planimeter the area is estimated by the

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[1] Science Abstracts 1900, No. 1179. [2] *Ibid*, No. 1179.

rolling of a wheel, and the side-slip of the wheel on the paper is ignored, the side-slip of the wheel on the paper is here eliminated and the area is estimated by the sidelong movement of the wheel on a bar carrying a graduated scale. This bar is made of a glass tube with scales marked on a piece of card sealed up inside, and is placed at right angles to that carrying the tracing-point. Three of these scale tubes are provided with the instrument, each marked with two different graduations; the mean effective pressure in an indicator diagram may therefore be read off directly for the springs in common use. A neat arrangement is provided for setting the instrument to any desired scale of measurement.

An elementary geometrical theory of the instrument is given in the Paper, also references to other explanations of the theory of planimeters.

A. S.

Comparison of Platinum and Gas Thermometers.

J. A. HARKER and P. CHAPPUIS.

(Roy. Soc., Proc. 65. 1899, pp. 327–329.)

In the words of the orignal, "The present Paper is the outcome of the co-operation of the Kew Observatory Committee and the authorities of the International Bureau of Weights and Measures at Sèvres, for the purpose of carrying out a comparison of some platinum thermometers with the recognized international standards.

"A new resistance-box, designed for this work, and special platinum thermometers together with the other accessories needed were constructed for the Kew Committee, and after their working had been tested at Kew, were set up in the laboratory at Sèvres in August, 1897. The comparisons executed between these instruments and the standards of the Bureau may be divided into several groups. The first group of experiments covers the range $-23°$ to $80°$, and consists of direct comparisons between each platinum thermometer and the primary mercury standards of the Bureau. Above $80°$ the mercury thermometers were replaced by a gas-thermometer constructed for measurements up to high temperatures. The comparisons between $80°$ and $200°$ were made in a vertical bath of stirred oil, heated by different liquids boiling under varying pressures. For work above $200°$ a bath of mixed nitrates of potash and soda was substituted for the oil tank. In this bath comparisons of the two principal platinum thermometers with the gas-thermometer were made up to $460°$; and with a third thermometer, which was provided with a porcelain tube, we were able to go up to $590°$. Comparisons of the platinum and gas-scales were carried out at over 150 different points, each comparison consisting of either ten or twenty readings of the different instruments.

"By the intermediary of the platinum thermometers a determination of the boiling-point of sulphur on the nitrogen scale was

also made. The mean of three very concordant sets of determinations with the different thermometers gave 445·27° as the boiling-point on the scale of the constant volume nitrogen thermometer, a value differing only 0·7° from that found by Callendar and Griffiths for the same temperature expressed on the constant pressure air scale.

"If for the reduction of the platinum temperatures in our comparisons we adopt the parabolic formula, and the value of δ obtained by assuming our new number for the sulphur-point, we find that below 100° the differences between the observed values on the nitrogen scale and those deduced from the platinum thermometer are exceedingly small, and that even at the highest temperatures the differences only amount to a few tenths of a degree."

R. A. L.

Magnetism of Bricks. O. A. Gage and H. E. Lawrence.

(Phys. Rev., November-December, 1899, pp. 304–309.)

The Authors tested the magnetism of a number of bricks (at least thirty-two) of various qualities. All but one—nearly white—were found to be magnets. The poles were never in the ends of the bricks, but either in the faces or edges. The magnetic moments of the bricks were not constant, but varied from time to time, when kept under normal conditions. Heating temporarily diminished the magnetic moments. It is surmised that the magnetism is due to the presence of magnetic iron oxide, either as a component of the clay or developed by heat, and that the permanent magnetism arises from the cooling of the bricks in the earth's magnetic field. The positions of the poles may be explained by the way the bricks are laid in the kiln.

A. G.

Influence of Velocity on Evaporation in Tubes. G. Halliday.

(Engineer, December 29, 1899, p. 653. Paper read before the Institute of Marine Engineers.)

This is the Author's second Paper on the heat-absorbing power of water in motion. In his first one[1] he showed generally that up to a certain point, when the source of heat is kept constant and the difference of temperature between the out-flowing hot and the in-flowing cold water is about 150° F., the number of thermal units which the water absorbs per minute increases steadily with the speed of flow. This effect is not greatly altered even when

[1] *Engineer*, vol. lxxxvii. p. 473.

the water is heated up to boiling-point, but the rate of absorption is less at that point than at 10° below it. With the apparatus then used, in which superheated steam was caused to heat the water flowing through a spiral glass tube immersed in the steam, there seemed to be a critical point in the velocity beyond which the thermal absorption fell away, sometimes very rapidly. That, however, was due to the heating powers of the apparatus being too limited to cope with the requirements of the water at the higher velocities employed.

In the present Paper the Author records experiments made with modified apparatus to test the rate of heat transmission with water which is freely giving off steam and is also made to flow through the apparatus at increasing velocities. The former experiments stopped at the boiling-point, so that the effect of a mixture of steam and water was not present in them. In this new series the water, previously heated to boiling-point in a tank, is made to flow upwards through a vertical copper tube heated by a Fletcher gas burner, the mixture of steam and water passing into a separator, from which the water goes to a measuring flask and the steam through a condenser to a graduated measure. The velocity of the water flowing through the heated tube and the quantity of water evaporated are expressed in cubic centimetres per 4 minutes—each experiment having been continued for that period. With a moderate flame at the Fletcher burner kept constant, and varying rates of flow of water, the following are some results:—

Velocity of Water.	Evaporation.
Cubic Centimetres.	Cubic Centimetres.
54½ per 4 minutes	24½
93 "	23
122 "	22
378 "	18
575 "	15
664 "	14
762 "	12

The character of the curves formed by plotting the results in various instances is practically the same, a larger amount of heat merely forming a curve at a higher level. The Author observes that (with the small tube used in these experiments) a velocity which gives an evaporation about equal to the quantity not evaporated seems to give the best result.

The Author concludes that whilst the quantity of steam evaporated depends on the quantity of heat supplied to the tube and on the velocity of the water through the tube, yet the greater the speed of the water through the tubes of a water-tube boiler the less will be the evaporation.

F. J. R.

Substitute for India-rubber. W. F. Reid.

(Soc. Chem. Ind. Journ., November, 1899, pp. 972–976. Discussion, pp. 976–977.)

A short account is given of the world's production of india-rubber and gutta-percha. The composition and properties of an artificial substitute (*velvril*) are described. This consists of nitrated castor or linseed oil mixed into a homogeneous mass with nitro-cellulose. It burns slowly, and is not explosive. The hardness can be varied with the composition. This material is more stable than either india-rubber or gutta-percha. Details of its specific insulation or dielectric strength are not given. It can be applied to wire either as tape or through a covering press. Its use for machine belting, hosing, cementing, varnishing, and for various special processes is described. A discussion followed.

L. B.

Study of Rotary Converters. E. de Marchéna.

(Écl. Électr., 1899, pp. 108–115: Industrie Électrique, February 10 and 25, p. 53, 1899. See 1899, Abstract No. 506.)

In this Paper the Author studies the special case of a rotary converter the P.D. across whose terminals is required either to decrease or else to increase with increase of load. In the first case a shunt winding is sufficient for exciting the machine; in the second, a series winding with or without a shunt winding is required. Assuming that the limits between which the load may vary and the corresponding limits of P.D. are given, and that the connection between the resultant ampere-turns acting on the field and the electromotive force is known (a straight-line relation being assumed within the given limits of P.D.), the Author develops an elaborate analytical and graphical treatment of the problem, by means of which the variation of the P.D., the power-factor, and the angle of lag between the current and electromotive force of the alternator supplying the converter, may be studied, as the load varies between the given limits.

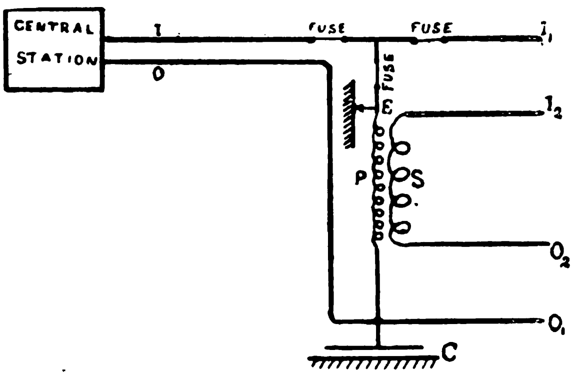
A. H.

Cable Breakdowns. G. Kapp.

(Elektrotechn. Ztschr., Dec. 28, 1899, pp. 896–900.)

Soon after the establishment of the first alternating-current central stations with networks of concentric cables it was found that the switching on or off of sections of the cables was attended with the danger of a breakdown in the insulation between the

outer main and the lead covering. It was also found that this danger could be avoided by following Neufeld's rule of always switching on the outer conductor first, and switching it off last. Breakdowns of the kind considered are due to resonance phenomena, and the Author fully investigates the conditions under which they become possible. He first considers the case of a concentric cable running out from the central station and supplying a transformer which feeds an isolated portion of the secondary network. Let C_1 stand for the capacity of the outer conductor with respect to the lead covering (*i.e.*, with respect to earth), and C_2 for the capacity, also with respect to earth, of the outers of the entire remaining portion of the network supplied from the same station. If we suppose that the station end of the outer conductor of our cable is disconnected while the inner still remains in contact with its 'bus bar, a current will flow as follows: From the 'bus bar through the inner conductor and the primary coil of the transformer to the outer conductor of the cable, thence (as a displacement



current) through the condenser of capacity C_1, next through the condenser of capacity C_2, and finally along the outer member of the remaining portion of the network to the station. Since C_1 and C_2 are joined in series, their joint capacity is $\frac{C_1 C_2}{(C_1 + C_2)}$, and if C_2 is very large in comparison with C_1 this becomes practically equal to C_1. It is obvious that since we have an inductive circuit (the primary of the transformer) connected in series with the condenser, powerful resonance may under certain conditions set in, and the dielectric of the cable be pierced. By considering some special cases such as frequently occur in practice the Author finds that resonance is not at all unlikely to take place, and that the danger of breakdown is a very serious one. A similar investigation with respect to stranded cables shows that in their case the danger is much less than with concentric cables. To avoid all risks of breakdown the Author recommends: (1) A strict adhesion to Neufeld's rule; (2) earthing of the outer conductor at a single

point; (3) omission of all safety fuses on the outer. Another class of breakdowns is then considered by the Author. This has only been known to occur in networks of concentric cables whose inner and outer members respectively are all connected together both on the primary and on the secondary sides. The breakdown is brought about not by the disconnection of the outer conductor, as in the first case, but by the development of an earth on the inner conductor. It is said that a breakdown of this second kind is much more serious than one of the first kind, the insulation being generally pierced in a number of places simultaneously. The accompanying diagram explains how the breakdown is brought about. P and S stand for the primary and secondary of the transformer, I and O for the inner and outer conductors respectively. Let an earth occur at E. All the fuses shown will blow, but the transformer, being still across the secondary network, will receive a current, so that P will be the seat of an electromotive force, which will give rise to a current flowing to earth, thence through the capacity C (that of the outer member O_1 of the network), and back to P. Resonance in this circuit may occur under certain conditions, with a consequent breakdown of the installation between O_1 and the lead sheathing. In this case the only reliable protection is to earth the outer at a single point (in order to avoid disturbance of neighbouring telephone circuits, and through a non-inductive resistance to prevent the occurrence of a dead short-circuit in case of accident), and leave out all safety fuses on the outer. A. H.

Best Number of Feeding-points in a Distributing Network.

A. Sengel.

(Elektrotechn. Ztschr., November 16 and November 23, 1899, pp. 807 *et seq.*)

The total cost of a network is made up of the cost of the feeding and distributing systems. By making the number of feeding-points very large the cross-section of the distributors may be greatly reduced, and thus the cost of the distributing system lowered—at the expense of the feeding system. On the other hand, by using a small number of feeding-points the cost of the feeders is reduced, while that of the distributors is increased. It is obvious that for a given distributing network there will be one particular number of feeding-points for which the total costs will be a minimum. The Author investigates this problem for networks consisting of square, triangular, and hexagonal meshes, and finds that the expressions obtained for the best number of feeding-points are practically independent of the shape of the meshes, but that they depend on whether the network is unbranched (*i.e.*, the feeding-points connected by simple lengths of distributors) or branched (*i.e.*, with a number of distributing

meshes connecting the feeding-points). The following formulas are deduced by the Author:—

$$F = \left.\begin{matrix}0\cdot5\\ \overline{1\cdot0}\end{matrix}\right\}\frac{A}{e}\sqrt{\frac{100\,b}{L\left(m+d+\frac{s}{2\,L}\right)p\,k\,\sigma}}$$

$$l = \left.\begin{matrix}1\cdot4\\ \overline{1\cdot0}\end{matrix}\right\}\sqrt{e}\,.\sqrt[4]{\frac{L\left(m+d+\frac{s}{2\,L}\right)p\,k}{100\,b\,\sigma}}$$

where F = number of feeding-points; A = total output of network in watts; e = P.D. at feeding-points in volts; $d+ba$ = cost of (single) cable, per metre length, of sectional area a square millimetres; L = length of (single) feeder; m = cost of laying a metre length of cable (not including cost of digging trenches or building conduit); s = cost of making feeding-point connections, and feeder connections at central station; p = total percentage drop along double feeder; k = conductivity of copper (= 57); σ = output in watts per square metre of network; l = distance between two feeding-points in metres.

The use of these formulas is illustrated by a numerical example. The upper figures (0·5 and 1·4 respectively) in the formulas are to be used for unbranched, and the lower (1·0 and 1·0) for branched networks. Where the load is distributed irregularly, it is best to subdivide the entire network into a number of districts (for each of which σ may be considered as constant) and apply the formulas to each district separately.

A. H.

Magnetic Observatories and Trolley Wires. S. WÄCHTER.

(Elektrotechn. Ztschr., 1899, pp. 655–657.)

A description of the double trolley line adopted in Strasburg to prevent magnetic disturbances due to traction currents. The forward and return conductors are placed 30 centimetres apart, and are supported by a compound insulator whose constituent parts are connected by a rod of insulating material. The cars are provided with double trolley poles. The arrangement is said to work satisfactorily.

A. H.

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TO THE

MINUTES OF PROCEEDINGS,

1899–1900.—PART III.

N.B.—Titles in italics refer to Original Papers, and those selected for printing only are further distinguished by the suffix "(S.)." *Abstracted Papers are not so indicated.*

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STAMFORD STREET AND CHARING CROSS.

LOA

PLATE 1.

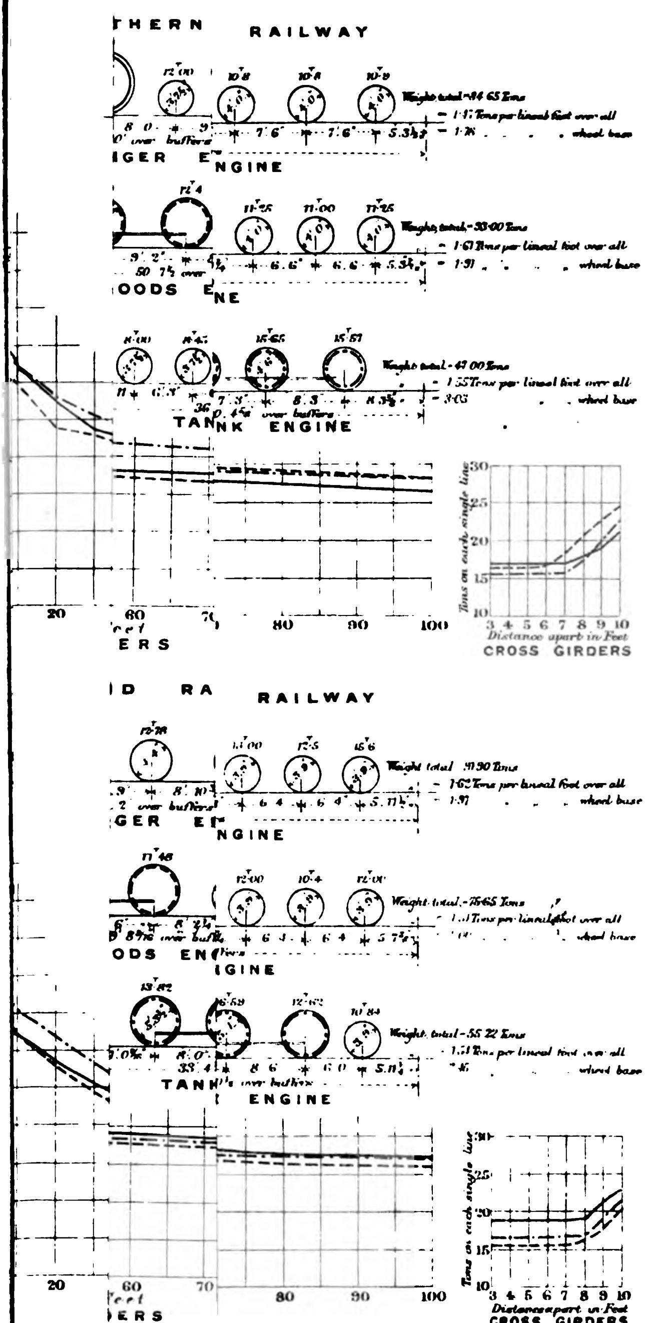
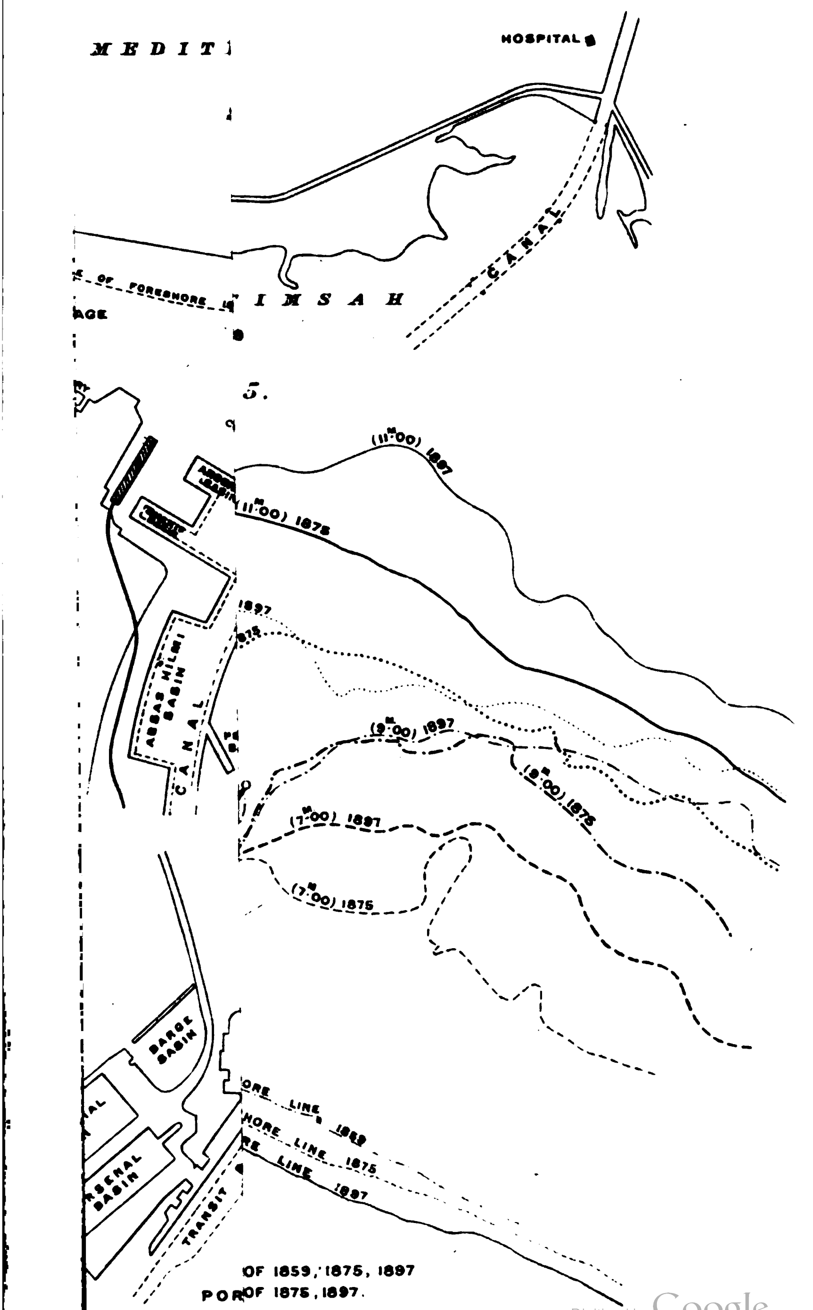

THERN RAILWAY
IGER ENGINE
Weight total - 44·65 Tons
OODS ENE
Weight total - 33·00 Tons
TANNK ENGINE
Weight total - 47·00 Tons
CROSS GIRDERS
Tons on each single line
Distance apart in Feet
ERS
D RA RAILWAY
GER ENGINE
ODS ENGINE
TANK ENGINE
Weight total - 55·22 Tons
CROSS GIRDERS
Distance apart in Feet
ERS

PLATE. 2.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OF 1859, 1875, 1897
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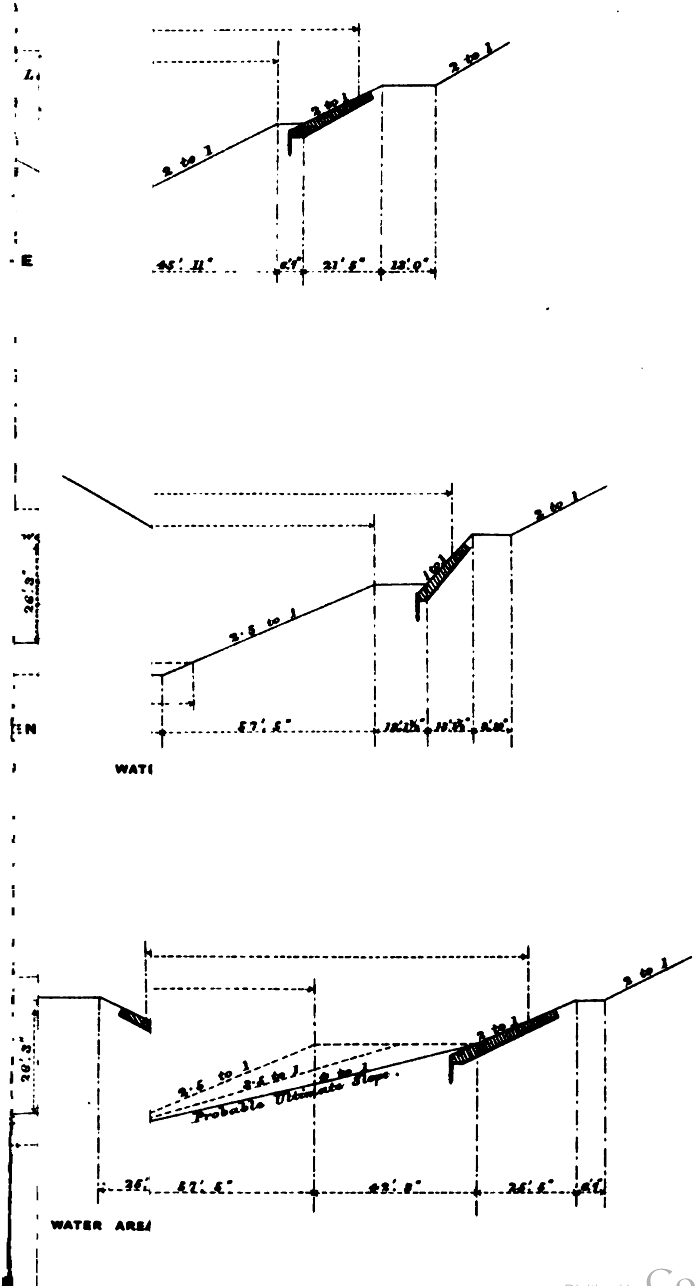
PLATE 3.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2 to 1
2 to 1
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QUEE

PLATE 4.

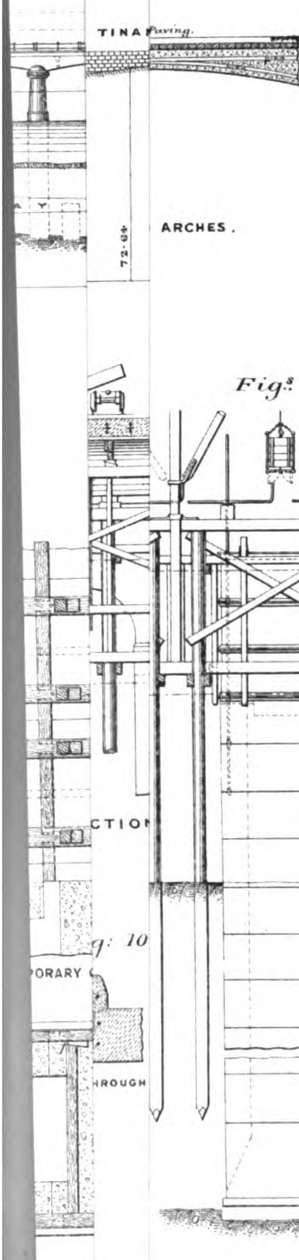
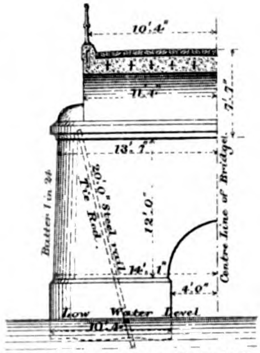
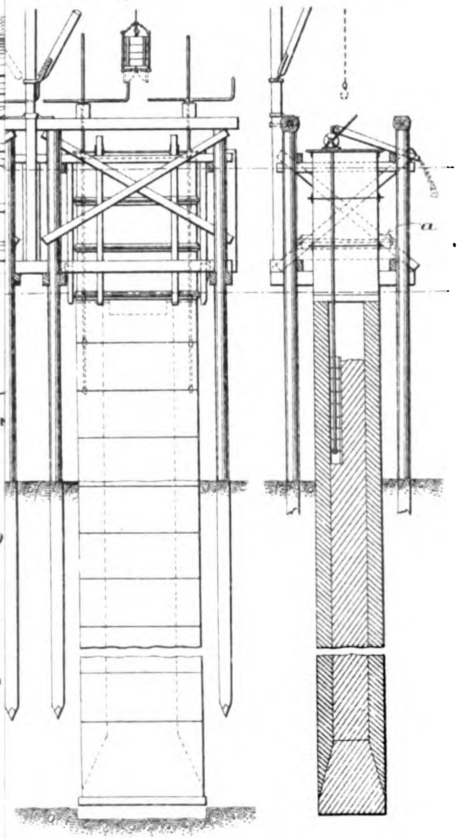


Fig: 4.



HALF CROSS SECTION OF BRIDGE.

Fig^s 9.



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